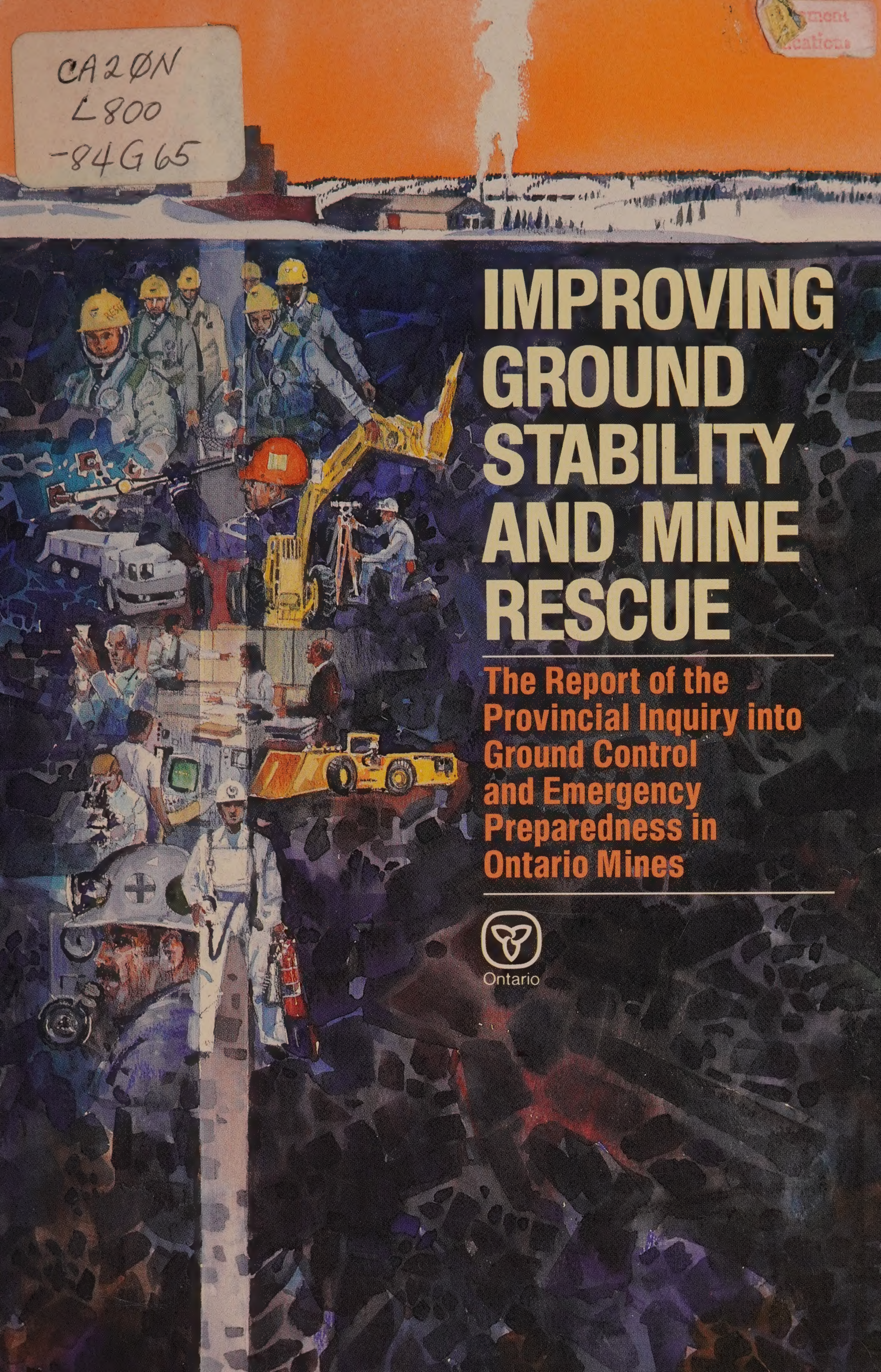

IMPROVING GROUND STABILITY AND MINE RESCUE

The Report of the Provincial Inquiry into Ground Control and Emergency Preparedness in Ontario Mines

Ontario

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The Report of the Provincial Inquiry into Ground Control and Emergency Preparedness in Ontario Mines

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MEMBERS

BRUCE CAMPBELL, Manager, Technical Services
Ontario Mining Association

PETER CURTIS, Staff Representative
Canadian Base Metal Workers' Union (C.N.T.U.)

RICK BRIGGS, President
Mine, Mill & Smelter Workers Union — Local 598

SIMON GUILLET, Staff Representative, National Office
United Steelworkers of America

STAN BHARTI, Superintendent, Mines Technical Services
Falconbridge Nickel Mines Ltd.

STEWART REID, General Manager
Campbell Red Lake Mines Ltd.

DAVE MELLOR, Staff Representative
United Steelworkers of America

MILT JOWSEY, Consultant
Mining and Mine Training

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SECTION 1

LETTER OF TRANSMITTAL

Provincial Inquiry into Ground Control
and Emergency Preparedness in Ontario Mines

260 Cedar Street
Sudbury, Ontario
Canada
P3B 3X2
Telephone:
(705) 675-4468

February 1986,

Hon. William Wrye,
Minister of Labour,
Ontario

Dear Minister;

On October 24, 1984, a Provincial Inquiry into Ground Control and Emergency Preparedness in Ontario Mines was established by your predecessor, the Hon. Russell Ramsay. This Inquiry has now been completed, and we are pleased to submit our report.

TREVOR STEVENSON
Chairman

BRUCE CAMPBELL

RICK BRIGGS

PETER CURTIS

STEWART REID

STAN BHARTI

DAVE MELLOR

SIMON GUILLET

MILT JOWSEY

TERMS OF REFERENCE

In April, 1981, the Report of The Joint Federal-Provincial Inquiry Commission into Safety in Mines and Mining Plants in Ontario was published. The Commission, known as the Burkett Commission after its chairman, Kevin M. Burkett, was appointed to investigate mine safety following a number of fatal accidents. In addition to a number of recommendations dealing with mine safety, the Burkett Commission recommended that a further inquiry into the adequacy of safety measures be made within three years.

Following the death of four miners due to a rockburst in June, 1984, and other ground control problems in Ontario mines, the Minister of Labour for Ontario, the Hon. R.H. Ramsay, appointed an *ad hoc* committee, with representatives from unions and the Ontario mining industry, to advise him on appropriate follow up measures in relation to the Burkett Commission recommendations.

The *ad hoc* committee reported on September 5, 1984, and as a result of its recommendations, the present Committee was established under Section 11 of the Occupational Health and Safety Act to conduct a thorough investigation of ground control practices and emergency preparedness in Ontario mines. The Committee was given the following terms of reference.

1 The committee shall investigate and report on matters related to ground control and emergency preparedness.

2 Under the subject of ground control, the following should be addressed:

a) Rock mechanics, including development of expertise locally at post-graduate level to insure the availability of such skills routinely to the Ontario mining industry.

b) Ground control including the development and provision of appropriate training and the availability of such trained individuals at all working levels.

c) New mining methods including pillar recovery methods, giving consideration to the development of new machines, automation or remote control techniques, blasting and backfill, lighting and communications.

d) Development of uniform monitoring standards applicable to workers' safety in the mine environment, including a review of available techniques and instrumentation.

3 Under the subject of emergency preparedness, the following would be addressed:

a) Matters related to first aid, procedures and equipment on emergency response, review of recovery procedures in non-fire emergencies and all such matters related to emergency preparedness.

4 The committee shall review all incidents of ground falls, rockbursts and other ground control problems that have occurred in the province of Ontario.

5 Recommendations shall be addressed to the Minister of Labour in an interim report by March 30, 1985, and a final report in eight months from the start of the committee's appointment.

The members of the Committee were Bruce Campbell of Toronto, Peter Curtis of Montreal, Rick Briggs of Sudbury, Simon Guillet of Toronto, Stan Bharti of Sudbury, Stewart Reid of Balmertown, Dave Mellor of Elliot Lake, and Milt Jowsey of Copper Cliff. D. Trevor Stevenson was appointed chairman. The federal government, through Energy, Mines and Resources Canada, contributed substantially to the expenses incurred by the Committee, and provided extensive co-operation in technical matters.

An interim report of the Committee's activities was made in April, 1985. This document constitutes the Committee's final report and recommendations.

ACKNOWLEDGEMENTS

The Committee wishes to acknowledge the very considerable contributions made by the many mining companies, unions, trade associations, agencies and institutions which responded to our request for written briefs.

Thanks are extended to the management and staff of the 15 mining operations which the Committee visited for the warm hospitality they extended to us. The hospitality of several local unions is also acknowledged; it was greatly appreciated.

Special acknowledgement and thanks are extended to Mr. Vic Pakalnis of the Mining Health and Safety Branch of the Ontario Ministry of Labour for the considerable contribution he made as special advisor to the Committee, and to Ms. Kirsty Cummins, who gave so unstintingly of her time to ensure that the Committee's activities were duly scheduled, on time, and properly recorded.

ACTIVITIES OF THE COMMITTEE

Immediately after it was appointed on October 24, 1984, the Provincial Committee of Inquiry into Ground Control and Emergency Preparedness in Ontario Mines began soliciting opinions and comments from a wide spectrum of organizations and individuals involved in mining or mining-related research and teaching.

In all the Committee contacted 46 mining companies or divisions of companies; 33 local or international unions; nine Canadian and three foreign government agencies; five mining trade associations or groups involved in mining research; seven individuals noted for their knowledge of ground control matters; and 19 mining schools and university faculties of engineering.

In response to these solicitations the Committee received 32 briefs and 16 other communications from companies, unions, researchers, government agencies, educators and individuals. Appendix IV contains a complete list of those who submitted briefs. The Committee also commissioned special expert studies of the education and employment of ground control engineers in Canadian mines; of ground control practices in other jurisdictions; and of ground control research conducted by Canadian schools and faculties of engineering.

The Committee spent 46 days conducting public hearings and discussions in every part of the province where mines exist. The chairman also conducted independent investigations both in Ontario and in other jurisdictions. The Committee visited and inspected 15 underground mines, and held meetings with officials of these operations. The Committee also met representatives of 25 local unions and one employee association.

The following report and its appendices are the results of this study, and have the unanimous agreement of the eight committee members and the chairman.

SECTION 2

INTRODUCTION

At 10:12 a.m. on Wednesday, June 20, 1984, a shock wave generated by a rockburst shook the Falconbridge Mine near Sudbury, Ontario, causing a backfilled stope to collapse. Four men were buried in the rubble of timber and cemented mill tailings. Rescue efforts were hampered by a series of subsequent tremors; in fact, the microseismic monitor installed at the mine recorded 10 significant events in the following 24 hours. One man was found alive, and after 27 hours of intensive effort under extremely dangerous conditions rescuers managed to release him almost at the moment he died.

This accident caused great concern in Ontario's mining industry, not only because of the nature and severity of the accident, but because Falconbridge was considered to have one of the most extensive ground control programs of any company operating a mine in Ontario.

The accident also provided a focus for many of the issues troubling mine workers in Ontario. It had been preceded by a long series of rockbursts in Quirke Mine in Elliot Lake, and it was followed by a rockburst only two weeks later at Creighton Mine in Sudbury. Together with the insistence of the United Steelworkers of America and the Sudbury Mine, Mill and Smelter Workers union, this led to the establishment of the Ground Control and Emergency Preparedness Committee.

HISTORY OF ROCKBURSTS.

Rockbursts are not a new phenomenon in Ontario mines. The first recorded burst in the Sudbury area was in 1929, and bursts occurred regularly in the Kirkland Lake area throughout the 1930's. In 1939 the Ontario Mining Association brought a world expert, Professor R.G.K. Morrison (later head of the mining department at McGill University) to advise on measures to reduce the hazard.

Also in 1939, the first seismic monitoring system was installed at an Inco mine. It was of limited value in improving ground control, and research for the next seven years concentrated on geological structure analysis, closure analysis, rock temperature changes and their relationship to stress changes, seismic velocity analysis, photoelastic model studies, and rock strength analysis.

Underground seismographs were also installed in the Lakeshore Mine in Kirkland Lake, with no greater success. None of the studies led to an ability to predict rockbursts, and it was concluded that it would be more productive to apply mine design and ground control criteria to inhibit and control rockbursts.

DEFINITION OF TERMS.

Before going further, it is desirable to define some of the terms which

will be used throughout this report. (A more complete glossary is found in Appendix VI).

A rockburst is defined in the Ontario Regulations for Mines and Mining Plants as:

> "an instantaneous failure of rock causing an expulsion of material at the surface of an opening or a seismic disturbance to a surface or underground mine."

Dr. David Hedley, Senior Scientist with the Department of Energy, Mines and Resources Canada, and one of Canada's foremost rock mechanics engineers, clarified this definition for the Committee by saying that a seismic event is a sudden release of energy, and that a rockburst is a seismic event that results in expulsion of material.

Seismic events are common throughout the world; they are usually called earthquakes, and they are caused by rock masses adjusting to the forces affecting them. In mining areas, these events are caused by the rock masses adjusting to the redistribution of stresses as ore is removed from the mine.

Dr. Hedley told the Committee that rockbursts could be placed in three broad classifications. First, and most common, are strain bursts, which miners call "popping" or "spitting" as small fragments fly from the rock face while work progresses. These small bursts rarely cause injury, but may be indicators of more serious problems to come. Second, there are pillar bursts, which can occur with little warning and result in extensive damage. Third are bursts caused by slippage along a geological fault. These are often the most serious, because little is known about the mechanism that causes them, and because they can release very large amounts of energy.

The mining regulations require mine managers to keep records of the occurrence of rockbursts or uncontrolled falls of ground, and to notify the Ministry of Labour when a rockburst occurs which causes damage to equipment or the displacement of more than five tonnes of material. (Incidents causing serious injury or death are reported under a different section of the regulations.)

A report provided by the Ministry to the Committee analysed the records of reports from 46 mines in Ontario. The Ministry report showed that in the five-year period ending in 1984, 31 mines reported no rockbursts/falls, seven reported 1 - 5 incidents, two reported 6 - 10 incidents, and six reported more than 10 incidents.

"Ground Control" is not defined in the Regulations, but in the context of mining operations it means the measures taken to limit the effect of rock movement.

The importance of ground control is demonstrated by accident

statistics. A report provided to the Committee by the Ministry of Labour (based on statistics developed by the Mines Accident Prevention Association of Ontario) shows that in the five year period ending in 1984, fall of ground accidents resulted in 18 deaths. In the 20 year period 1965 - 1984, there were 82 deaths from falls of ground.

This means that about one-third of underground fatalities result from falls of ground; this is the largest single category of underground fatalities.

FIGURE 1. FATALITY HISTORY 1920 - 1984

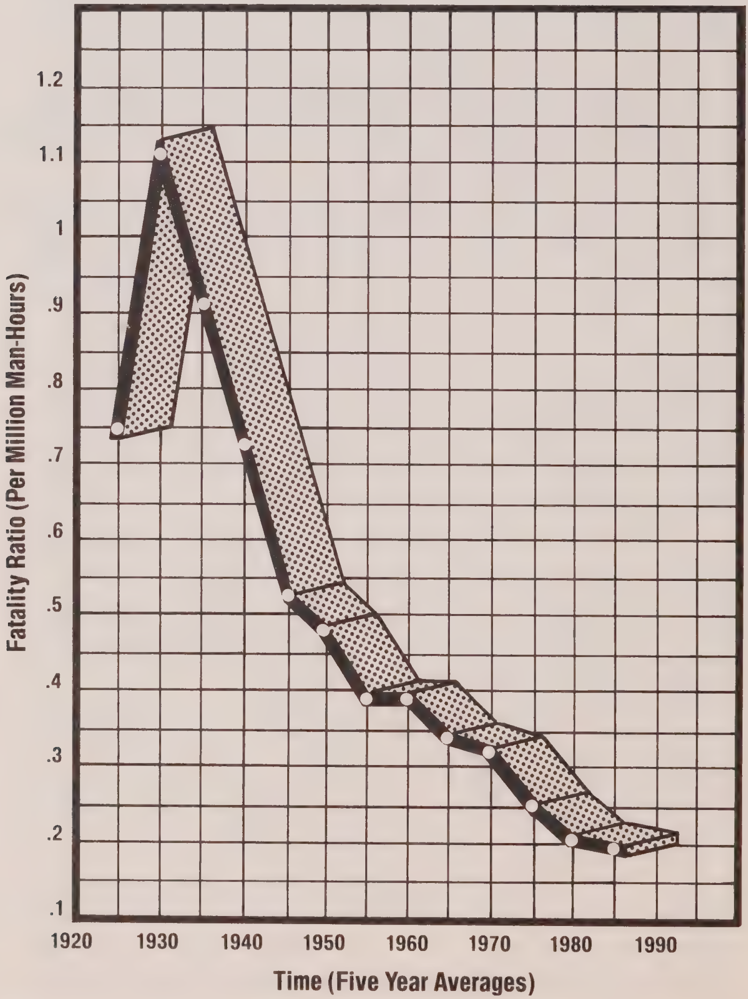


FIGURE 2. FALL OF GROUND FATALITIES 1965 - 1984

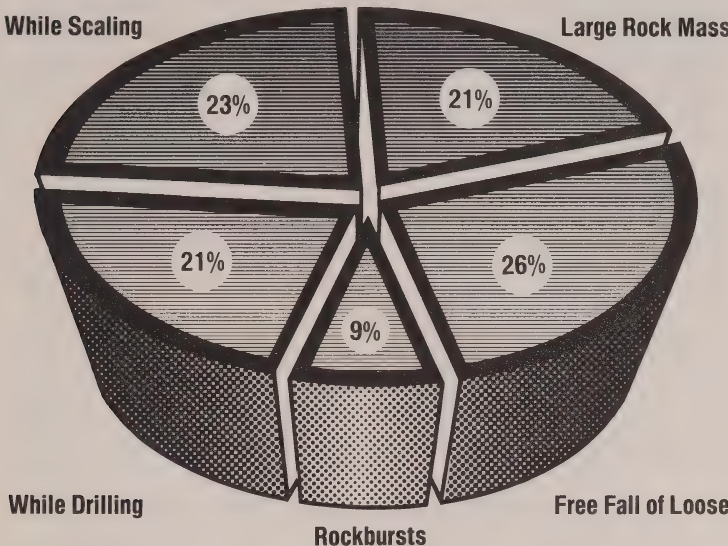
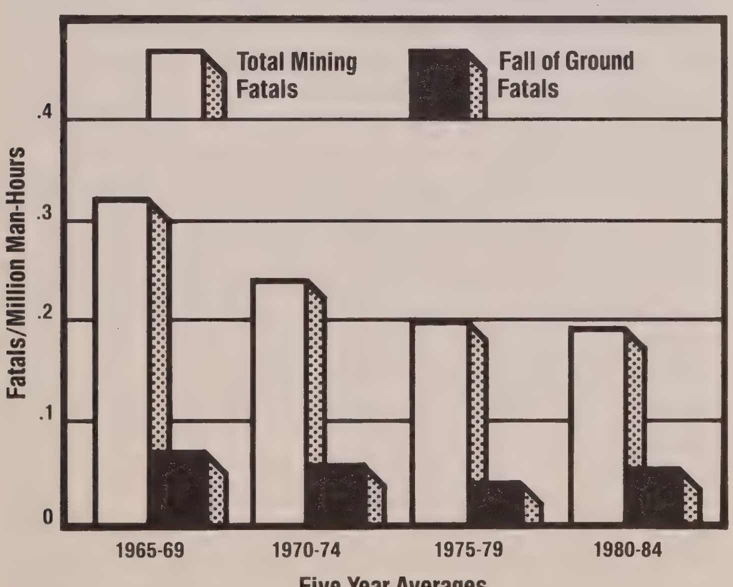


FIGURE 3. TOTAL MINING FATALITIES VS. FALL OF GROUND FATALITIES



TYPES OF HAZARDS

Ground control problems are caused by mining. As rock is removed from the mine, two major types of hazards are introduced: the first is the hazard of loose pieces of rock on the walls and roof of the newly blasted mine opening, which may fall on workers; the second is the redistribution of stresses in the rock mass, which may result in large-scale movements of the rock.

The first hazard is dealt with by the miner, who scales or bars down loose pieces, installs rock bolts or timber, places screening, sprays gunite, pours sand fill, or takes other measures appropriate to the particular situation. The second hazard is more difficult to deal with, and is determined by the way the mine is designed.

For purposes of analysis and discussion of preventive measures, fall of ground accidents are divided into two sub-categories which relate to the types of ground control hazards discussed earlier. First are accidents caused by "unexpected" falls, and second are accidents involving scaling, failure to scale, while drilling or rockbolting, and so on.

Efforts to improve safety in the second sub-category — accidents connected with routine ground control procedures — have been increased over the years. A comprehensive miner training program, developed by a tripartite committee made up of labour, management and government, has established performance standards which are common throughout the hard rock mining industry. Better mine planning, increased mechanization and more intensive supervision have helped. Joint Health and Safety Committees and Worker Safety Representatives provide ways for workers to contribute to the solution of these problems. In some mines, particularly base metal mines, changes in mining methods to remove workers from high-hazard areas have resulted in significant improvements in safety.

However, accidents in the first sub-category, unexpected massive falls of ground, continue to take a steady toll. In the five-year period ending in 1984, there were three accidents resulting in eight deaths in this category, while in each of the preceding five year periods, there were two accidents resulting in two deaths.

This type of accident — sudden, unexpected, totally beyond the influence of the worker, and very often fatal — is regarded with a special horror by workers in mines.

MICRO AND MACRO GROUND CONTROL.

It would be useful at this point to discuss a concept presented to the Committee by Dr. William Hustrulid of the Colorado School of Mines, who was retained by District 6 of the United Steelworkers of America.

Dr. Hustrulid said that one should divide ground control procedures into two categories, micro-ground control and macro-ground control. By micro-ground control he meant measures related to the immediate working area in which the miner has the responsibility for maintaining safe conditions, and his brief discusses the means by which a miner carries out these responsibilities.

The term macro-ground control refers to measures related to the rock mass over which the miner has little, if any, control — measures affecting the stability of pillars, stopes, panels or sections. This aspect of ground control, Dr. Hustrulid said, is the responsibility of the mine design engineers and the operational management which ensures that the design is properly executed.

However, it is not enough for management to design the mine and carry out the plans, Hustrulid emphasized. While many companies have their own in-house expertise, or use consultants to ensure that proper ground control procedures are followed, the workers and worker representatives are often left uninformed. When copies of reports are given to worker representatives, explanations of the significance of the reports must be given in understandable terms.

The occurrence of ground control problems in 1984 in Ontario, centered particularly in Sudbury, Elliot Lake, and Balmertown, raised the concerns of mine workers. Workers underground, both miners and service personnel, who hear the noise of a rockburst and feel the rock shake around them, naturally want to know what is going on, and how their own safety is affected. Lack of information in terms understandable to workers and Health and Safety Committee members raises serious doubts about management's willingness or ability to deal with these problems.

However, it is a mistake to regard the subject of ground control only as a safety issue, because it can have a substantial effect on productivity and ultimately on the life of the mine.

It was noted from the many union briefs submitted to the Committee that workers and their representatives are sincerely concerned about safety. It was also noted that mine managers are equally concerned about production. There was a perception on the part of some people appearing before the Committee — not a majority, and not all from one side or the other — that the twin concerns of safety and production are separate, distinct issues.

This question was dealt with by the Joint Federal Provincial Inquiry Commission into Safety in Mines and Mining Plants, the Burkett Commission. The dichotomy between safety and production is false, the Commission said, and summed the issue up in the title of its report, "Towards Safe Production".

This Committee endorses that view; we believe that the mining industry of Ontario will be greatly enhanced when all parties understand that safety and production are equally important, and cannot be considered separately.

During its discussions with mine workers' representatives the Committee also found a profound unease about the apparent lack of ability to quickly rescue injured workers or recover bodies in cases of massive falls of ground or collapses of mine backfill. While the present system of mine rescue is considered more than adequate for the purposes intended, it must be recognized that its primary function is to respond to emergencies caused by mine fires, not disasters involving massive falls of ground.

CLASSIFYING THE ISSUES.

In its investigations, the Committee found that the issues could be divided into broad categories, as follows:

- Developing an ability to predict and prevent rockbursts.
- Education and training of mining company employees at all levels, in matters relating to ground control.
- Sharing information with those who need and want it.
- Preparing for extraordinary emergencies.

Dr. William Hustrulid, quoted earlier, told the Committee that "the mining methods, procedures and equipment used in Canadian mines are some of the most advanced in the world. They have a history of good mining practice, and innovative techniques."

However, events have shown that there are shortcomings, and this report is an attempt to help the mining industry overcome these deficiencies.

DESCRIPTION OF INCIDENTS

THE FALCONBRIDGE MINE ROCKBURST

At 10:12 on the morning of June 20, 1984 the first of a series of seismic events triggered the collapse of backfill in an undercut-and-fill stope about 4200 feet underground at the Falconbridge mine near Sudbury. Four miners were trapped in the fill; three died almost instantly and the fourth died about 27 hours later, just after being extricated by his rescuers.

It is not the intent of the Committee to give a complete account of the rescue attempt, which has been described elsewhere. (See the transcript of the Inquest into the Deaths of Richard Chenier, Daniel Lavallee, Sulo Korpela and Wayne St. Michel). The rescue was conducted under extremely hazardous conditions, and the Committee acknowledges and commends the skill and bravery of the rescue workers, who set a new standard for dedication and courage. Our purpose is to examine the events which preceded and followed the accident, and to draw from it conclusions which may prevent similar accidents in the future.

Undercut-and-fill, the method of mining being used in the stope where the four miners were killed, involves extracting a block of ore by mining successive cuts, working from the top down. At Falconbridge Mine, wide stopes are mined in panels with a maximum width of 15 feet. Cut heights are typically nine to 10 feet. When a panel has been extracted a "sill mat" consisting of a combination of timbers and screen is placed on the floor, and a mixture of cement and classified mill tailings is poured to fill the open area. After the fill has hardened the next cut is taken by mining below the sill mat. The cemented fill is self-supporting, but timber posts or caps are used for extra support.

This method of mining is used where ground conditions do not permit working under unsupported backs. In the area where the accident occurred there had been problems with conventional cut-and-fill mining, and mining was temporarily suspended in 1980.

The Falconbridge Mine is one of several nickel mines owned and operated in the Sudbury area by Falconbridge Ltd. Mining was begun in 1929, and by 1984 about 94 per cent of the ore had been removed. Seismic activity has been recorded since 1955, with the number of events ranging from none to more than 60 per year in 1983.

In 1981 a microseismic monitoring system was installed in the mine in preparation for mining the internal hoistroom pillar, one of the few large blocks of ore remaining in the mine. The hoistroom pillar is located between the 3675 and 4025 levels of the mine. It should be noted that the purpose of the microseismic monitoring system was not to predict rockbursts, as it was recognized that the technology is not

capable of doing that. However, the system did provide an accurate record of seismic activity in the mine prior to the fatal accident of June 20, 1984.

Most of the seismic events during 1983 caused no damage, or resulted in displacements of less than one tonne of rock. However, in September of 1983, a large seismic event which displaced approximately 1500 tonnes of rock was recorded. On June 14, 1984, a seismic event with a local Richter magnitude of less than 1.0 was recorded approximately 120 feet from the stope in which the accident occurred. No damage was found.

The level of microseismic activity was not considered to be unusual between June 14 and June 20. However in the third week of June — immediately before the fatal accident — signs of excessive ground pressure (split timbers and drift closure) were found by the joint Health and Safety Committee along the 4000 and 4200 levels. At 5:00 a.m. on June 20 a seismic event was recorded on the 3800 level, but was apparently not large enough to warrant being reported to the mine supervisor.

Then, without further warning, a powerful earth tremor with a magnitude of 3.4 on the Richter scale shook the entire mine, and caused the collapse of the backfill in the nearby stope where the four miners were working. In the next half hour 116 microseismic events were recorded, and shortly after noon a series of large seismic events temporarily interrupted efforts to rescue the trapped men.

A committee of technical experts from Canada, the United States and South Africa was gathered to examine the underground workings to help determine the cause of the rockbursts. The microseismic monitoring system located the epicentres of the events along a series of faults in the immediate area, and the technical committee concluded that the rockbursts occurred when a very large mass of rock moved suddenly along what is known locally as the Ore Pass Fault and the #1 Flat Fault. The energy generated when the rock moved from one-half to two inches along these faults would be sufficient to cause a tremor of the magnitude recorded at 10:17 on June 20.

The committee's conclusion was confirmed when another large seismic event — 2.5 on the Richter scale — occurred on July 5. The technical Committee immediately inspected the #1 Flat Fault at the 3500 level of the mine, and found fresh evidence that the rock had moved about two inches. When the chief executive officer of the company could not be assured that a similar event would not occur in the future he closed the mine.

THE CREIGHTON MINE ROCKBURST

At 1:25 pm on July 6, 1984, the largest seismic event ever recorded in the Sudbury Basin — magnitude 4.0 on the local Richter scale — occurred in Inco's Creighton Mine. This event was followed by a series of smaller rockbursts, up to a magnitude of 2.5, over the course of the following week.

Mining at Creighton began in 1901, through a succession of ever deeper shafts. At present the bottom working level is 7000 feet below the surface, and the ore is open at depth. The first recorded rockbursts occurred in 1934, in stopes at the 2300 foot level. Inherent stresses caused rockbursts in new development headings below the 2600 foot level, and ore passes have been a source of rockbursts as shallow as the 1300 foot level. There has also been a history of rock bursts related to two different rock formations, known locally as quartz diorite and trap dykes. There is no record of deep fault-related rockbursts at the Creighton Mine.

Data from a micro seismic monitoring system in the lower levels of the mine indicated that the first event on July 6 was located about 500 feet into the hanging wall between the 3200 and 3400 levels of the mine. Subsequent events probably took place in the footwall, between the 3200 and 3800 levels. Damage was located mainly in the access drifts from the 3200 to 3800 levels in the #5 Shaft area.

Mining had stopped a week prior to the first rockburst, because of a scheduled four-week summer shutdown. Microseismic activity declined for the first three days after the shutdown followed by a slight, probably not significant, increase beginning July 4.

Due to the size and unique nature of the July 6 seismic event, a panel of experts in rockbursts and underground seismicity was assembled to investigate and make recommendations regarding future mining in the area of the event. This panel included three of the six experts who investigated the Falconbridge accident, just two weeks previously.

The panel concluded that the most likely mechanism of the major event was shear slippage on the western edge of an existing hanging wall subsidence zone. This changed the stress patterns in the area, resulting in the subsequent rockbursting. The mine management decided to stop mining in this area.

CAMPBELL RED LAKE ROCKBURSTS

On December 30, 1983, a series of rockbursts occurred in the "F" zone of the Campbell Red Lake Mine. The rockbursting continued for about 12 days; in all, 22 events were large enough to be recorded on the national seismic network. The largest rockburst had a magnitude of 3.3 on the local Richter scale.

The "F" zone, an isolated orebody within the mine, had been closed about December 20 because the miners had reported that the ground was "working", or making noises that indicated something was going to happen. As a result, there were no workers in the area and no injuries in the December 30 incidents.

The first recorded rockbursts at Campbell Mine occurred in 1965 in the "A" zone, when the boxhole and sill pillars were being removed. Mining is done by shrinkage stopes, developed by driving boxholes and installing manually operated timbered chutes on 27 foot centres — along the ore zone. The boxholes are joined 23 feet above the track, leaving a series of triangular pillars along the drift between the chutes.

These boxhole pillars, and the 14 foot thick sill pillars which support the working level, are in ore, and it was the recovery of this ore which caused the bursting in 1965. Prior to 1970, the bursting in the "A" zone was in the shrinkage area and directly attributable to sill and boxhole pillar removal. However, in January and February of 1971, 59 boxhole pillars were reported to have burst in the area of a cut-and-fill stope on the 11th level, against the party wall.

In July, 1981, the first rockburst in the "F" zone was recorded. It occurred in a sill pillar on the 11th level, and there were a small number of subsequent rockbursts until the events in late December of 1983 and early January, 1984.

The early bursting incidences in the "F" zone of 1981 prompted the decision to purchase a microseismic system. Geophones were placed in a tight pattern around active workplaces, and it was data from these geophones that helped in the decision to remove the crew 10 days prior to the major bursting.

THE QUIRKE MINE ROCKBURST

Quirke Mine has been experiencing severe ground problems since March, 1982, when a series of rockbursts occurred in the mined out "C" reef trackless area. The affected area has gradually increased outward as pillars in the area continue to deteriorate. The affected area at present measures about 1800 feet north-south, by 4000 feet east-west.

The ore body at Quirke mine dips about 26 degrees to the south, and consists of two conglomerate reefs averaging 12 feet thick. The "C" reef lies about 140 feet below the "A" reef. Mining is done by the room-and-pillar method, conventionally using jackleg drills and slushers, or by trackless means using drill jumbos and scooptrams. Stope blocks are laid out normally on 150 foot centres, with rooms 50 to 65 feet wide, separated by 10 to 30 foot centre and rib pillars. The thickness of the pillars depends on the thickness of the ore reef, which can vary from six to 30 feet. Maximum extraction ratios are limited to 85%.

The conglomerate reefs are intersected by a few major faults and many minor faults. Bedding plane slips occur in the immediate hanging wall in a number of locations.

A block of ore was left unmined in the "C" reef due to an excessive slushing distance, and it was decided to test trackless mining equipment in this area to see if it could be used eventually in mining the "A" reef. In order to facilitate the trackless equipment, pillars had to be realigned on apparent dip.

Mining commenced in this block in March, 1975, and was completed in April, 1979. In mid 1981, stress related failures in the trackless area pillars were noted; the area of disturbance radiated outward and by March, 1982, rockbursting was occurring to the extent that mining crews had to be removed from the area. As noted above, the affected area is now 1800 by 4000 feet.

It is believed that the cause of the pillar failures was the change in support orientation, resulting in a reduced ability to transfer stress. Mud-coated faults in the area could be a complicating factor.

It should be noted that the affected area is close to the boundary pillar between Quirke and Denison Mines; on the Denison side of the boundary was a repair shop which was hit by the energy waves generated by the pillar failures on the Quirke side.

SUMMARY

The Falconbridge and Creighton rockbursts were thought to be triggered by the movement of very large masses of rock along a shear zone. The Quirke and Campbell rockbursts were thought to be triggered by pillar failures under great stress. These, with the strain bursts mentioned briefly in the introduction, are the three types of rockbursts described by Dr. David Hedley.

MINING IN ONTARIO — BACKGROUND

There is a great diversity of mines in Ontario. The Committee visited 15 mines in the course of its investigation, about one-third of the number in production, and while every mine had similarities, there were also significant differences.

Orebodies in Ontario vary widely in size and shape. The massive nickel-copper sulphide deposits in Sudbury are more than 7000 feet deep (the bottoms of some have not been found), up to 200 feet wide, and more than 1000 feet long. These deposits are generally steeply dipping at perhaps 70 degrees or more from the horizontal.

The flat-lying salt deposits in Southern Ontario extend hundreds of miles; mining takes place in beds 25 to 40 feet thick. The lateral extent of the mines is limited only by the extent of the mining lease.

Uranium is mined at Elliot Lake from quartz pebble conglomerates laid down as flat beds (like beds of gravel) and subsequently folded into a trough which dips to the west. The north limb of the trough emerges at Quirke Lake, about six miles from the town, and the south limb emerges at Nordic Lake, five miles south of town. The ore body passes under Elliot Lake at a depth of about 4000 feet.

Gold is mined generally from narrow vein deposits which may be almost vertical, inches thick and only a few feet long and high. It is the multiciplicity of these vein formations that makes the mine.

Every mine has a shaft to provide access to the orebody, crosscuts and drifts (horizontal tunnels) to develop individual workplaces, raises (vertical or steeply dipping tunnels) for ventilation systems, movement of ore and waste, emergency escapeways, and so on. These are called development headings, and in an average mine there may be 200 miles of them.

The workplaces where the ore is mined are called stopes, and these may vary in width from three or four feet in a narrow-vein gold mine to a hundred feet in a uranium mine. Length and height also vary according to the shape of the orebody.

It is obvious that there are limits to the size of opening that can be made in rock; this is what rock engineering, more often called rock mechanics, deals with. A mine operator is in a dilemma; he wants to operate his mine as economically as possible, and yet he cannot jeopardize the safety of the mine — or the workers in it.

If an orebody is larger than can be safely mined with one single opening, then the mine is divided into many openings separated by solid rock (or ore). The primary opening is called a stope, or panel, and the separation is called a pillar.

The mining method is determined in part by the geometry of the

ore body; large ore bodies will allow for a greater degree of mechanization than narrow, vein-type deposits. A good description of the many types of mining methods is contained in a booklet, "Guide to Underground Mining," published by Atlas Copco.

Mining methods in common use in Ontario are Shrinkage Stoping, Cut and Fill Mining, Blasthole Stoping, Vertical Retreat Stoping (or Vertical Crater Retreat), and Room and Pillar Mining.

The Ministry of Labour provided the Committee with a list of 42 underground mines which were operating in Ontario in January, 1985. Nine of the mines used the Room and Pillar method; three used Shrinkage Stoping, and 22 operated with a mix of Blasthole, Vertical Retreat and Cut and Fill Mining. The remainder used a combination of Cut and Fill and Shrinkage Stoping.

Of the 42 mines:

- 1 produced less than 200 tons per day.
- 4 produced 200-499 tons per day.
- 13 produced 500-2000 tons per day.
- 24 produced more than 2000 tons per day.

Two consulting firms, Steffen Robertson & Kirsten (B.C.) Inc. and Golder Associates, were retained by the Committee to survey rock mechanics and strata control practices in Canada, the United States, South Africa, the United Kingdom, Germany, Australia, Sweden and Finland. A short summary of their report can be found in Appendix II.

SECTION 3: Special Issues

RESEARCH

Much effort has been expended to develop methods of predicting and preventing seismic events such as rockbursts. To date this effort has not been successful, and there is no reliable method of predicting rockbursts.

The Committee retained consultants to investigate the status of rock mechanics research in Canada and other countries. The consultants reported that "Canada and Ontario have a sound technical foundation in most areas of rock mechanics in their research organizations, universities and industry."

However they also found that there are serious problems in communicating the results of research projects to the mining industry, and in ensuring that research is done on the issues which are of concern to the industry. The effect of failure to communicate research results effectively is delay in applying those results, duplication of effort, neglect of important areas, and misdirected resources.

The following quotations, from consultants giving confidential testimony, sum up the consensus on research:

- "Individual mines can't put enough talent together to do a good job on research."
- "Simply setting up a research organization won't solve all the problems. Canada has all the elements, but the initiative to organize them has been lacking."
- "Research must be managed, not just the flow of money. It is important to have a technical group of people as a controlling body."
- "CANMET (the Canadian Centre for Mining and Energy Technology) can't respond if industry can't agree on priorities."

The Committee made its recommendations on research with these remarks in mind. The consultants, representing the most knowledgeable rock engineering organizations in four countries, were quite explicit: leadership in mining research should be provided by management and labour. In the absence of this leadership, government and other organizations will try to fill the void, with less than optimum results.

Many of the larger mining companies in Ontario conduct extensive research. However, while none of the many programs appeared to be proprietary in nature, there seems to be little exchange of information between the various companies and organizations conducting mining research. Appendix I describes some of the research projects that have been conducted by mining companies in Ontario, and it is clear that considerable work is being done — but is being done in isolation.

Universities, government agencies and consultants are also doing research. However, the consultants retained by the Committee state that there is "a severe communications problem" between the industry and the institutions involved in mining research. The Committee agrees with the consultants on the basis of its own experience.

At the same time, there is another communications gap, between management and workers, about rock mechanics research. Dr. William Hustrulid, consultant for the United Steelworkers of America, pointed out that it is not enough for management to improve mine design/execution/control procedures, it must also communicate in understandable terms to the miners and service workers so that they will feel confident about their safety at work. "Communication," said Dr. Hustrulid, "is not just handing a report to a miner." The point that Dr. Hustrulid made so eloquently was repeated many times by workers and their representatives during the Committee's hearings.

Despite the amount of research that is being done at the present time, there are still areas where the development of new techniques and new expertise is required. Specifically there is a need to develop techniques to predict rockbursts accurately, to improve counter measures and protective measures, and to improve the stability of underground workings by various methods such as better sequencing, support systems, backfilling and emplacement of fill.

Some of the research which will lead to the solution of these problems is being conducted outside of Canada, and more effective means of disseminating the research applicable to Ontario's mining industry should be developed. Substantial improvements in both production and safety could be achieved with better research management.

In order to ensure that research addresses real problems, and is applicable to existing conditions in Ontario mines, the mining industry itself — both management and labour — should be involved in policy direction. An independent research body, funded by the mining industry, the provincial and the federal governments, is needed to address fundamental research and applied research projects which are too large for individual mine budgets.

RESEARCH ORGANIZATIONS

HDRK Mining Research Ltd. HDRK Mining Research Ltd. is a corporation established in 1983 by four mining companies (Falconbridge Ltd., Inco Ltd., Kidd Creek Mines Ltd. and Norands Inc.) to conduct research on new mining methods and equipment directly related to the production interests of the companies. It is primarily concerned with longer-term innovative methods which are too risky for any of the individual companies to develop alone.

The group has access to the combined staff and resources of all the participating firms, and contracts out some of the research while using the mines as research facilities. The research has direct application to the member companies' operations. To date HDRK has not directed its resources towards rock mechanics research.

In-House Research. Several of the larger mining companies have rock mechanics service groups. The personnel have a good blend of experience and academic qualifications, and also have access to specialized testing equipment and computer facilities.

While many of the projects handled by in-house staff are of interest to the rock mechanics community, the transfer of technology is impaired by the failure to publish results in a useful form. In addition these groups rarely pursue projects which do not have an immediate payback in terms of solving a specific problem.

Consultants. Mining consultants provide services similar to those provided by in-house research personnel; indeed, many companies prefer to use consultants rather than set up their own groups. Consultants also combine academic and experience qualifications, and have excellent access both to testing and computing facilities. However the same limitations on publishing and otherwise disseminating research results applies to consultants.

Universities. Universities also conduct mining research and would like to do more. But — with some notable exceptions — there are serious problems in university research, mainly concerned with the university-based researcher's lack of practical experience. A survey of twelve Canadian universities was conducted; the majority of university staff members had some industrial experience but it was usually of short duration and often not in mining.

The level of funding for university-based research is very low, considering the importance of the mining industry to Canada. A number of researchers commented that they had considerable

difficulty in obtaining financial support from the mining industry for fundamental research, but many acknowledged that they had not made the attempt to interest the industry because they had limited contacts with people in authority. Some also admitted that they were not particularly effective at communicating and interpreting the results of their research.

In summary, while it is apparent that some university-based researchers are effective in attaining industry funding, selecting appropriate topics, and communicating the results, in general university research in rock mechanics is highly dependent on the individual researcher's personal contacts and ability to communicate. Research appears underfunded in view of the mining industry's importance to the Canadian economy, and is almost totally uncoordinated.

CANMET. CANMET, the Canadian Centre for Mining and Energy Technology, is the premier government-sponsored mining research organization in Canada, and as such has had a long history of useful contributions to the mining industry. It is part of Energy Mines and Resources Canada, and has a very broad mandate: CANMET is required to transfer technology to industry, to participate in technology development, to provide national testing and research facilities, and to maintain contact with the provincial inspectorates. CANMET's interests also include the development of mining standards in conjunction with the inspectorates and other regulatory agencies.

However the resources — especially manpower — available to carry out this broad mandate are very limited. In spite of this CANMET feels obliged to respond to requests for site specific help from industry, and as a result it frequently finds itself carrying out work which can only loosely be termed research.

CANMET also admits that it has a communications problem with the mining industry. It is making a major effort to overcome this problem. The consultants reporting to the Committee stressed that if CANMET had a problem, it was shared by the mining industry, which did not seem to know exactly what it wanted from its national research organization.

EDUCATION AND TRAINING

For this part of the Committee's report it is convenient to distinguish between education and training. Rightly or wrongly, when the term "education" is used, we mean the effort to impart knowledge in a formal course at a college or university. When the term "training" is used, we mean a similar effort at or in a mine. Both education and training can be given at any level of an organization.

Regardless of the terms used, there was almost universal agreement among the mining people who discussed the issues with the Committee that more knowledge is needed by more people about ground control and rock mechanics. In light of this, the Committee commissioned a consultant to review the state of rock mechanics education in Ontario.

The consultant reported that only Queen's University in Kingston offers a post-graduate course in rock mechanics specifically for mining engineers. The Mining Engineering Department at Queen's is by far the oldest and largest in Ontario and ranks amongst the top ten in the western world. Giving Queen's the highest praise, the consultant said that rock mechanics was treated as an integral part of mining. He had seldom encountered such a degree of integration of rock mechanics and mining anywhere in the world, and, he said, "it is an interesting glimpse of what should be the norm."

The University of Toronto, while it does not offer a mining degree, does have a highly competent teaching staff and outstanding research facilities in rock mechanics, in the Department of Civil Engineering. "The mining industry," the consultant said, "would do well to remember the availability of this highly competent rock mechanics group."

Laurentian University, right in the heart of the mining industry in Sudbury, has several advantages for providing educational services to the mining industry. With an enthusiastic, albeit inexperienced staff, there is a great need for industry support and sufficient funding for experienced staff — a good mining generalist, perhaps — to provide an overall perspective.

There are two mining colleges in Ontario. Haileybury School of Mines, part of Northern College, is the older and has an integrated program of mining, geological and metallurgical engineering technology. Cambrian College, in Sudbury, separates the three disciplines to give more intensive education in each subject. Each approach has its advocates.

The consultant gave both colleges high marks for the ability of their teaching staff and the approach to teaching rock mechanics at the college level.

It has to be recognized, however, that an examination of only Ontario colleges and universities is misleading, given the nature of the mining industry in Canada. First, graduates from post secondary institutions often move from one province to another, and second, Canada benefits from the talents of a significant number of mining people from other countries.

There are at least 14 Canadian universities that provide mining-related rock mechanics courses. Most of the universities with full mining departments require students to complete at least one course in rock mechanics, and the majority provide post-graduate courses for rock mechanics specialists. The quality of the courses varies, but the overall quality of undergraduate and post-graduate education is satisfactory, and the number of engineers graduating with these qualifications is sufficient to meet the requirements of the industry in Canada. So far as the availability of rock mechanics engineers is concerned, the Committee's consultant simply stated that "there are certainly enough mining graduates with a background in rock mechanics produced by Queen's University alone to satisfy the needs of all the mines in Canada."

It should be noted at this point that various industry presentations showed a concern about the qualifications of academic staff teaching rock mechanics. The general lack of practical experience to support theoretical knowledge was of great concern to mining company managers. This concern was shared by the Committee's consultant.

SHORT COURSES

To this point the discussion has focussed on rock mechanics education for undergraduate and post graduate students. There is an additional need, identified by both consultants and a number of managers to upgrade the education of people already working in the mining industry.

Short courses are a useful method of improving the knowledge of rock mechanics for mining engineers and others. Good examples of these short courses are found in Australia; courses currently offered in Ontario are considered to be less thorough and less systematically organized.

One suggestion made by the Committee's consultant is that the mining industry of Ontario should establish a steering committee to organize, coordinate and endorse short courses in rock mechanics. These courses should apply specifically to the needs of Ontario mines, and be taught by instructors with both academic skills and practical experience.

TRAINING

In addition to the education and training required by engineers and technologists, the Committee identified a need for training in ground control and rock mechanics for workers. Dr. William Hustrulid, speaking on behalf of the Steelworkers union, told the Committee that "miners should receive improved training in rock mechanics so that they could recognize the potential for structurally controlled ground failures. It is undoubtedly a good idea for miners to have the ability to recognize more deep seated potential failure zones. That is, there may be wedge blocks which, when sounded with the scaling bar seem to be intact but, when given a certain amount of time and/or extension of the length or width of the drift, these wedge blocks daylight or loosen, giving the potential for a major roof fall."

Mr. Leo Gerrard, at that time the staff representative for the Steelworkers union in Elliot Lake, expressed the same idea in slightly different terms. "The ultimate responsibility rests with the employer," he said, "but workers can have effective input only when they are effectively trained." He went on to give a number of examples of workers who had taken training (often at their own or at union expense) and then went on to contribute to the health and safety of their fellow workers.

The Committee heard from the members of the CNTU at Geco Mine who had taken seminars in Sault Ste. Marie and Thunder Bay, paid for by their union, to become effective health and safety committee members. Similar stories were heard in other mining camps.

PRESENT TRAINING PROGRAMS

In 1975 the mining industry began an investigation into a comprehensive miner training program. With specialized help from the appropriate branch of the Ministry of Colleges and Universities (now called the Ministry of Skills Development), a committee made up of representatives of the Steelworkers union, the Mine Mill union, and the Ontario Mining Association developed a list of desirable skills for miners. The need that had been identified was to train new miners in basic skills, to reduce the rate of injuries in the first few months of employment.

Performance demonstration standards were developed for each of 10 skill areas, and these standards became known as the Common Core for Basic Underground Hard Rock Mining Skills, usually called the Common Core. In recognition of the fact that each mining company has different needs, different conditions, and different methods, the exact training program was left to the individual company to develop.

Companies are free, under the system, to reach the objectives — the performance demonstration standards — in the way that suits them best.

In 1979, with the passage of The Occupational Health and Safety Act and the Regulations for Mines and Mining Plants, mining companies were required to train all new underground miners in the Common Core.

Many companies, having noted the success of the program with new employees, are requiring other miners to demonstrate their skills to the same standards outlined in the Common Core, and to date more than 11,000 underground workers are accredited by the Ministry of Skills Development.

The Mining Tripartite Committee which developed the Common Core has gone on to develop a Specialty Skills program of advanced training, and to date miners have completed about 4500 modules in this program. In addition, a common core program for underground supervisors has been developed, a mill operators' training program is almost complete, and a "Common Core Program for Underground Soft Rock Miners" has been completed.

While this training effort has been going on, the Ministry of Labour's Mining Health and Safety Branch — in co-operation with the Mines Accident Prevention Association of Ontario, and representatives of labour and management — has developed modules for use in training mine inspectors, health and safety committee members, supervisors, and worker-inspectors. The Ontario Mining Health and Safety Training Program has produced 39 modules on hazard recognition and inspection practices in Ontario mines. The Mines Accident Prevention Association of Ontario has also developed a ground control course aimed at first line supervisors and health and safety committee members.

In addition, Haileybury School of Mines has developed a short course in ground control which it gives to its mining students each year, and also to supervisors and technologists from mining companies.

All these programs are aimed at miners, mining supervisors, and mining technologists — logical, and laudible. However, in a modern mechanized mine, almost half the employees working underground are not miners, in the narrow sense of the word. They are mechanics, electricians, pipefitters, geologists, surveyors, samplers; a great number of skilled people who are subject to the same working conditions and some of the same hazards as the narrowly defined "miner."

The Committee found that in many instances these people are forgotten, or at least put low on the list of priorities for training in the elementary skills of mining. One of these elementary skills is in the area of ground control; which can be defined as those measures required to keep rock — ore, loose, ground, or whatever term is used — from falling on somebody.

The Committee believes the mining industry, using the existing organizations that have developed modular training programs in several areas, should improve training in ground control for everyone working underground.

COMMUNICATIONS

The Committee was asked to address the question of new methods of communication, as they affect ground control. During the discussions with the different groups of mining people the Committee met around the province, it became apparent that the word "communication" had two fundamental meanings. Some people used it in the sense of equipment, the technology by which the message is transmitted. Others meant the information which is shared in the process of communicating.

Neither part of communications, the equipment which is used or the information which is shared, seems to be easy when it comes to ground control issues, but with thought and effort it should become easier.

First, equipment. There is a need in underground mines to develop an economical, reliable and effective method of communicating between a central location and the individual workplaces. There is equally a need to be able to pass a message in the opposite direction.

This need has been recognized for many years, both for the protection of workers in case of emergency, and for production efficiency. There has been world wide research into the problems generated by the underground environment, and many systems — at least twenty — have been tested in Ontario. To date none have been deemed satisfactory.

An underground mine can have hundreds of miles of workings on 40 or more levels, each connected by two or more vertical shafts. It is not practical to run electrical wiring throughout the mine; if it were practical, it would not be safe to introduce the electrical hazard into wet, congested workings. New blasting technology reduces the hazard of stray currents somewhat, but it is still considered an undesirable situation to have electricity around blasting operations.

There are two main communications methods used in mines now. First, a telephone system connects each shaft station with the surface; often this system is extended to lunchrooms and refuge stations underground, which are usually located between the shaft and the active workings. Some mines have telephone systems underground connected to the Bell Telephone system on the surface.

Second there is the stench warning system which is used in case of a mine fire or other dire emergency. When the stench, ethyl mercaptan, is injected into the compressed air lines and the mine ventilation system, miners in the remotest areas of the mine know within minutes that they should seek refuge.

There are problems with both these systems. The telephones are not located in the workings, because it is not practical to have wires

running throughout the mine. The stench is a "one-way" system which may give the wrong message, depending on the circumstances. For example, emergency procedures may call for workers to gather in underground refuge stations when stench is released; this may be appropriate in the case of a fire, but it may also be dangerous in the case of a large rockburst. Questions have also been raised about the possible toxicity of ethyl mercaptan.

The answer probably lies with radio technology; while many mines have experimented with various types of radio, no one system has yet proven to be universally effective or reliable.

Previous commissions of inquiry have recommended that miners working alone or in remote locations have an efficient system of communication available in case of emergencies. The need for improved means of communication has also been recommended by a succession of coroner's juries investigating mining deaths. The Committee believes that the mining industry should give a higher priority to the development of effective radio communications underground.

The second part of communications is the information to be shared. The Committee heard from many local unions that workers needed and wanted more information about matters that affected them. Mr. Leo Gerrard, staff representative of the Steelworker's union in Elliot Lake, pointed out that mine workers are intelligent people who, when they have the required information, are more than able to make a significant contribution to the enterprise.

The Committee heard that in some mines managers failed to tell workers about specific hazards they were likely to encounter as mining progressed, that they didn't systemically provide an opportunity for miners to provide important information to mine design engineers, that specific groups — particularly tradesmen — of underground workers were left out, and that workers on cross shifts often failed to keep each other informed. In fairness, the Committee heard of many instances where there was a good exchange of information.

However, it is believed important to stress this single point: the responsibility for effective communication, for ensuring that the message is properly understood, and that adequate methods exist for receiving and evaluating feedback from the miners rests with mine management.

MINE DESIGN

Mining is an ancient skill. The first mines were begun in the Stone Age, perhaps 15,000 years ago. Tunneling for copper ore began about 5000 years ago, and some 2000 years ago a road tunnel near Naples, Italy was driven through 4000 feet of rock. However, it is only in the past 50 years that mines have been systematically "designed," and only in the past 20 years have there been significant developments in the science of rock mechanics.

The process of design in rock is particularly difficult. The rock mechanics engineer is not working with a material of known strength and consistency, like reinforced concrete, but with a complex assemblage of different materials, influenced by equally complex geological structures and affected by applied stresses that change as mining progresses.

Engineering rock mechanics is not an abstract study in mathematics or mechanics; it is a high-level applied engineering science. It can be successful only when the actual geological conditions are effectively integrated into the design of the mine.

In the past 20 years, the development of comprehensive failure theories for intact and fractured rock, powerful numerical computation techniques, and laboratory equipment capable of very sophisticated material property determinations have helped to advance the science of rock mechanics. However, applying much of the new technology to complex three-dimensional underground structures in heterogeneous rock masses is generally difficult without significantly simplifying certain assumptions, which reduces the fidelity of the conclusions.

At the same time, there is a variety of numerical modelling techniques that can approximate excavation behaviour under simple boundary and loading conditions. The limitation of these techniques lies in the ability of the engineer to provide accurate input data.

The Committee was briefed at length by the technical experts of Noranda Inc. on the subject of rock engineering for ground control. These experts stated that Noranda's operations policy is:

a) some level of applied rock mechanics is necessary at each operation;
b) the most immediate benefit of applied rock mechanics comes from the proper application of sound observational rock engineering in the work place; and
c) operations personnel must have access to outside technical expertise through either in-house groups and/or outside consultants.

The Noranda brief to the Committee advocated comprehensive design techniques for planning a mine. Such a program would have four stages: determination of the rock mass properties; determination of the loading conditions; computer modelling; and monitoring.

"In applied ground engineering," the Noranda people said, "the importance of communications cannot be overstated. There is no question, for instance, that the most knowledgeable personnel concerning ground conditions are the miners themselves. Directly 'feeling' the response of drills, observing the effects of blasting, the response of various supports, etc., on a day-to-day basis, is the 'front line' of rock engineering. The problem is in translating this wealth of experience into a format that can be used in mine engineering. This is potentially the most important function of the mine ground control engineer."

The issue of mine design was also discussed by Dr. William Hustrulid, who said "there are a number of ways to go through a design. (One approach) uses a minimum of data in the form of structural geology, rock mechanics measurements, or equations as part of such a design process, and a maximum amount of experience in similar types of ground, size of equipment considerations, etc. Another type of design might be based on the use of elaborate mathematical models which can faithfully reproduce very complex geometries and allow the introduction of complex stress fields, material properties, etc.... Clearly there is a middle ground between designs based upon the technical feeling and those based upon elaborate mathematical models."

The most important thing, Dr. Hustrulid emphasized, was that the basis for the design be fully documented, so that if ground control problems were subsequently encountered, the design basis and the design could be re-examined and corrective actions could be taken.

On the question of the role of the miner in mine design, Dr. Hustrulid told the Committee that miners should be told why the design is as it is, but that design is the responsibility of the company. While the individual miner is responsible for "securing his particular work area," and he should "have the ability to recognize more deep seated potential failure zones," the stability of pillars, stopes, panels or sections is the responsibility of mine design engineers, geologists and management.

Mine design is therefore a continuous process of planning, informing, doing, observing, modifying and repeating. In retrospect, the lack of adequate design principles has led to some poorly-designed mines, and this has resulted in unsafe and uneconomic situations.

The effective integration of rock mechanics engineering into mine planning and design will help to reduce the incidence of ground control problems and rockbursts. It is not possible, given the current level of knowledge, to completely eliminate rockbursts, but the rewards for reducing their impact on mining operations are significant.

EMERGENCY PREPAREDNESS

In February, 1928, fire broke out in a stope in the Hollinger Mine in Timmins, Ontario, with disastrous consequences. There was no protection against the toxic gases an underground fire produces, no procedures in place to warn or to rescue workers, and no way to put out the fire.

While most of the men underground at the time of the fire managed to save themselves, thirty-nine did not, and died of asphyxiation. This was Ontario's worst mine disaster.

Rescue crews from the United States Bureau of Mines in Pittsburgh responded to a call for help; they arrived in Timmins very quickly with a railroad car full of equipment, and in less than an hour, without going underground, were able to tell the mine management how to control the situation. This was a lesson which didn't need to be repeated. The Ontario mining industry organized a mine rescue system which is now considered to be among the best in North America.

The mine rescue organization is managed by a Senior Mine Rescue Officer in the Ministry of Labour, with the assistance of eight district Mine Rescue Training Officers. Mining companies are assessed by the Workers' Compensation Board of Ontario for their share of the cost of the rescue organization, which in 1985 amounted to just under $1 million. This amount includes the costs of salaries for training officers, supplies, vehicles, equipment and buildings. The costs of training individual team members — currently some 1000 volunteers — is borne by the individual mining companies.

There are eight mine rescue districts in the province, with seven fully equipped stations (Southern Ontario is served by the Sudbury station) including vehicles. In addition 35 sub-stations located at various mines have enough equipment for mine rescue teams to get into immediate action in case of a mine fire.

The members of the mine rescue teams are chosen for their outstanding qualities of intelligence, initiative, strength and stamina, good judgment and willingness to accept great personal risk to save the lives of others.

Mine rescue training consists of a three-day basic course, a three-day standard course, and an advanced training program over a two-year period following the standard course. There are also courses for supervisors and managers. All active team members receive eight hours of training every two months to keep their skills at a satisfactory level.

Training is done with a variety of breathing apparatus, using an

array of mine rescue tools, and practicing fire fighting and first aid techniques.

The purpose of mine rescue in Ontario is, first and foremost, to save lives in the event of a mine fire. In this, the organization is exemplary: only one life has been lost in an underground fire since the system was set up in 1931. The secondary purpose is to minimize damage to the workings and equipment by extinguishing the fire as quickly as possible. Again, the record shows that Ontario's mining industry owes a great debt to its mine rescue teams.

With this acknowledged, we are brought to a significant point. The mine rescue system is aimed at underground fires, and not other types of emergencies which can, and have, occurred.

During presentations by various labour organizations to the Committee, two accidents were mentioned frequently. Most attention, of course, was focussed on the Falconbridge collapse of fill accident in 1984 which was the event which triggered this inquiry. Of almost equal concern was the massive fall of ground accident in 1980 at Denison Mine in which three miners died.

While the causes of the accidents were quite different — the Denison accident was not caused by a seismic event — the results were similar. In both cases miners were buried under massive amounts of material, making rescue and recovery impossible to accomplish quickly with the equipment currently available, without endangering the lives of rescuers who were already working at great risk.

Almost every group making presentations to the Committee was asked the same question: "What kind of emergency equipment do you think is needed, that is not now available?"

Answers were disappointing in a way, but showed the need for concentrated thinking on the issue. Several people said that before equipment could be designed, the problem had to be defined; however, there are so many different types of mines and methods of mining in Ontario that it is difficult to develop standardized equipment suitable for all circumstances.

The Committee examined two different situations involving rescue equipment.

First, the U.S. Bureau of Mines has a central warehouse of emergency equipment located in Pittsburgh, Pennsylvania. This equipment has been purchased to meet the perceived needs of a shallow, flat-lying sub-surface coal mining industry, and one of the key pieces of equipment is a large diameter drilling machine. Without going into unnecessary detail, the Committee believes that such a

centralized storage of emergency equipment is not appropriate for Ontario.

The second situation the Committee examined arose from a mine disaster in the Province of Quebec in 1980. The mining industry of Quebec, represented by the Quebec Metal Mining Association, has developed a detailed response plan in the event of a mine catastrophy. The name of this plan is "Operation Catamine" — Catastrophe Miniere.

There are four main parts to Catamine:

- Identification of potential disasters, and development of prevention programs.
- Mine evacuation plans.
- Rescue procedures.
- Identification of resource people and special equipment available.

"Operation Catamine" was explained to the Committee by Mr. Edward Legault, who helped to develop it under the auspices of the Quebec Metal Mining Association. "Mining people by themselves cannot handle a disaster," Mr. Legault told the Committee. "We have between 500 and 600 people inside and outside Quebec who have volunteered to help — police, Bell Telephone, medical and civil authorities."

Following Mr. Legault's advice, the Committee simply recommends that the mining industry of Ontario look carefully at "Operation Catamine." As a minimum there should be a list, widely circulated and regularly updated, of the resources — people and equipment — available for an emergency other than a mine fire.

Since the equipment necessary to rescue or recover miners quickly from under massive falls of ground or collapses of fill apparently does not exist, it is necessary for some organization to develop this equipment. Alternatively, there may be suitable equipment in some unknown source.

The Committee believes that the Ministry of Labour's mine rescue organization should be responsible for the task of developing sources for equipment.

At the same time people must be trained to use this new equipment. Again, the Committee sought the advice of the people making presentations to it. There was no consensus, but two fundamental points of view emerged.

First, there was the "full pail" theory; that knowledge and skill is put into a person much like water into a pail, with a finite limit. There was a concern that one human being could not absorb all the training required for both fire and non-fire emergencies, and that the rescuer would not be able to operate at the level of intensity required. Over and over the statement was made that "we don't want to do anything to lessen the effectiveness of our mine rescue teams," which are perceived to be excellent.

The other point of view could be called the "good man" theory, which holds that if a person has the innate qualities of intelligence, strength, initiative, stamina and compassion, that person can be trained to do anything, and can absorb any amount of training.

It was noted by the Committee that district Mine Rescue Officers are already training for some non-fire emergencies. The Committee believes that the rescue training system already in place should be expanded under the policy direction of industry representatives, and that the selection of people to be trained should be determined by local mine management.

MINE LIGHTING

Poor lighting is rarely the primary cause of underground accidents, but it can be a contributing factor. Since 1976, nine coroner's juries investigating deaths in mines have recommended improved lighting as one means of improving safety conditions. While lighting conditions play some role in many mine accidents, they are felt to have special significance in accidents involving ground control problems, and especially falls of ground, since poor lighting makes it easy to miss dangerous conditions that could otherwise be corrected. This was one of the findings of the Burkett Commission, which concluded that "improved lighting would reduce the risk of accidents."

In 1981 the Mining Health and Safety Branch of the Ministry of Labour began investigating underground lighting conditions, and in 1982 to investigate lighting conditions at accident sites where poor lighting was thought to be a factor. In August 1984, the branch began investigating lighting conditions at all fatal accidents.

In addition, the Mines Accident Prevention Association of Ontario (MAPAO) has prepared two papers on mine lighting which give examples of lighting levels required for specific tasks, and summarize guidelines established by the Illuminating Engineering Society. Table 0.0 (found on page 4-7 of MOL brief) summarizes the results of the MAPAO survey of lighting conditions. As the survey shows, only the lighting at one location (refuge stations) met the minimum requirements for "easy" tasks; none of the locations tested met the requirements for "medium" or "difficult" tasks. It is clear that lighting in Ontario mines is not adequate, at least by the standards established by the Illuminating Engineering Society.

That conclusion is supported by the investigations into lighting conditions at accident sites conducted by the Mining Health and Safety Branch of the Ministry of Labour. Of the seven investigations completed by December of 1984, poor lighting was found to be a contributing factor in two, or approximately 30 per cent.

It should be noted that adequate lighting is not merely a question of *enough* light, but also a question of the right kind of light. For example, following one accident investigation by the MHSB, unshielded lights were installed along a conveyorway. But the glare from the unshielded lights may actually have made visibility worse, and conditions more dangerous, than before. Similarly, glare from the surface of the rock may conceal fractures and cracks; in those cases, use of high-intensity lights close to the surface to be checked may actually impair visibility.

Lighting in permanent surface installations in Ontario mines is governed by Regulation 252 for Mines and Mining Plants, which specifies certain levels of illumination. Requirements for underground working areas are governed by Regulation 252, which rather than demanding specific levels of illumination, requires that illumination shall be "effective" in all areas "where the nature of the equipment or the operation may create a hazard due to insufficient illumination."

Obviously there is considerable room for dispute about what constitutes "effective" illumination. More stringent requirements have been legislated in other jurisdictions. For example, British Columbia requires 21.5 lux in all tunnels, shafts and inclines, and 53.8 lux in all heading areas. The U.S. Federal Coal Mining Regulations also specify a minimum luminance for all workplaces.

The Mines Accident Prevention Association of Ontario is currently preparing a report on mine lighting for the Mining Legislative Review Committee of the Ministry of Labour. (The M.L.R.C. is a standing committee of representatives of management and labour appointed by the Minister of Labour to advise on regulations for mines in Ontario). It is perhaps time for Ontario to replace vague statements about 'effective' illumination with regulations specifying the minimum acceptable level of underground lighting.

TABLE 1. ONTARIO MINE LIGHTING SURVEY

(SOURCE: "Mine Lighting in Ontario" — MAPAO 1983)

Location	Number of locations surveyed	Illuminance measured (lux)	IES Recommended illuminance levels for easy, medium and difficult tasks (lux)
Shaft Stn.	10	33	200-300-500
Refuge Stn.	8	131	100-150-200
Haulageways	5	13	50-75-100
Conveyorways	5	13	50-75-100
Garages	13	101	200-300-500
Maintenance Shops	4	155	200-300-500
Crushers	9	152	200-300-500

SECTION 4: Conclusions and Recommendations

1. RESEARCH

FINDINGS AND CONCLUSIONS

A significant amount of research is being conducted in the field of rock mechanics and ground control by mining companies, government agencies, and universities, and by other institutions and associations both in Canada and around the world.

There is a great deal of sharply-focused research at the company level, but there is no effective co-ordination of this research, and often the results do not become widely known. Because of the great diversity of mines the results of research at one company may not be applicable to another, but there is still a need for systematically publishing results for the benefit of the entire industry.

While further research in all aspects of ground control is needed, and should be encouraged, this Committee identified a number of specific areas which require special attention. These are outlined in the recommendations.

During the course of its investigations the Committee became convinced that there is a need for a research institute which would receive policy direction from a group of senior mining executives, with input from representatives of labour and government. This research institute would be funded by the mining industry, with the assistance of government, and be directed by a technically-competent Executive Director.

Its purpose would be to ensure that research which relates to the practical problems of ground control in Ontario mines is conducted, and it would achieve this goal not by conducting research itself, but by arranging for research to be conducted by providing funding for worthy projects. The creation of such a research co-ordinating body is one of the principal recommendations of this Committee.

RECOMMENDATIONS

1.1 **That mining companies be encouraged to continue conducting independent research programs as they see fit.**

1.2 **That mining companies, with the support of labour and government, establish a research organization to act as a central body to co-ordinate research into ground control and rock mechanics in Ontario mines. This co-ordinating body shall be managed by a Board of Directors made up of members currently active in the industry and representing all facets of it — management, labour and government. The Board**

would appoint an Executive Director who, with an appropriate staff, would manage the research coordination and be accountable to the Board. The initial program would cover at least the following areas:

a) Identify ground control problems in Ontario mines;
b) Identify needed research and the appropriate agencies to conduct it;
c) Contract for the necessary research to be done, and supervise its quality;
d) Ensure that the results of the research are published on a regular basis so that mine management, appropriate labour representatives and government agencies are fully informed; and
e) Participate in the development of guidelines for the implementation of safe ground control practices.

1.3 This organization shall be funded by mining companies operating in Ontario, and by the federal and provincial governments.

1.4 Among the subjects the organization shall consider for funding are the following:

- Rockbursts
- Destressing
- Backfill (including quality monitoring and backfill testing methods)
- Scaling
- Pillar design and recovery
- Blasting (including vibration damage and drilling controls)
- Ground support (including rockbolting and mechanical supports)
- Monitoring and testing of ground conditions
- Mine Lighting
- Computer modelling
- Equipment design and mechanization as it applies to hazardous ground conditions.

2. TRAINING

FINDINGS AND CONCLUSIONS

The *Common Core for Basic Underground Hard Rock Mining Skills* program was developed to equip a miner with the minimum skills necessary to work safely in standard mining operations. The *Specialty Skills* program was developed to supplement the basic skills in specific tasks. Both programs were based on the premise that only with on-the-job training and an opportunity to practice the newly-learned skills would a new miner become a safe and productive worker.

The Committee considers these programs adequate for the purposes for which they were devised. However, there is an identified need for improved training in advanced ground control for miners and supervisors, and in basic ground control for underground tradesmen, such as electricians and mechanics.

The Committee has also identified the need for ground control training for members of the joint health and safety committees who work underground, and believes that this training should be similar to that given to supervisory personnel.

RECOMMENDATIONS

2.1 That a separate section on ground control be added to the skills included in the Common Core training for new underground miners.

2.2 That the present tripartite committee established to approve modular training programs shall expand those programs to include specialist modules on ground control for all underground miners.

2.3 That all miners receive periodic refresher courses in ground control if required. Labour shall be encouraged to participate in the development of the curriculum.

2.4 That miners who have been off the job for one year or more should be evaluated with respect to their knowledge of current ground control practices, and should receive appropriate training where necessary before they return to regular underground work.

2.5 That non-miners working underground be trained in the fundamentals of ground control, including the recognition of potential hazards.

2.6 That all mining supervisory staff receive adequate training in ground control. The ground control module for supervisors being developed by the tripartite committee on modular training shall be deemed adequate for this purpose.

2.7 That health and safety committee members shall receive the same training in ground control as supervisory staff.

3. POST SECONDARY EDUCATION

FINDINGS AND CONCLUSIONS

The general conclusion of the Committee's investigation of post-secondary training in ground control is that the programs available do not focus adequately on the practical problems encountered in actual mining situations. The number of educational institutions providing training in ground control and rock mechanics is adequate to meet the needs of the mining industry for people with technical or university qualifications. The undergraduate and post-graduate programs offered in those institutions give students an adequate understanding of the theoretical concepts of rock mechanics. But they do *not* give students an adequate understanding of the applications of those theories to practical mining problems.

The Committee identified a number of reasons for this. In general, universities offering undergraduate programs in rock mechanics lack the facilities to teach practical ground control. In addition, undergraduate programs do not incorporate ground control subjects into the overall curriculum to a sufficient extent. The instructors in those programs often lack practical mining experience, perhaps because university hiring practices emphasize academic qualifications more than on-the-job experience. It is the conclusion of this Committee that these hiring practices are inappropriate.

As a result, while the number of engineers with graduate and post-graduate qualifications is sufficient to meet the needs of Ontario's mining industry, there is a shortage of people with both professional qualifications and suitable practical knowledge of ground control. One reason for these difficulties is that the funding of colleges and universities offering graduate and post-graduate training is not adequate to permit them to meet the needs of the mining industry, both in terms of research and in terms of the technical preparation available to graduates.

These shortcomings also extend to the short courses offered in subjects related to ground control. There are not enough of these courses, there is a need to focus them more carefully on specific groups within the industry — for example, the course given to graduate engineers is not well-suited to supervisors — and there is a need to make the courses more accessible by providing them in locations close to working mines, including mines in remote regions of the province.

Mining companies can encourage and support improved education in rock mechanics, both by direct support of university

programs in mining, and by ensuring that graduates of rock mechanics courses are fully incorporated into line and staff functions of mine management.

RECOMMENDATIONS

3.1 That colleges and universities training mining engineers recognize that good undergraduate teaching in a subject such as rock mechanics demands lecturers who have a deep understanding of the subject, solid practical experience in its application in real mining situations, and the ability to present their material in clear and simple terms which will enable the students to apply their knowledge to the solution of the problems they will encounter in the industry.

3.2 That the teaching staff in colleges and universities with rock mechanics programs shall have strong practical experience in underground hard rock mining.

3.3 That qualified personnel from the mining industry participate in teaching graduate and undergraduate programs at colleges and universities with rock mechanics programs.

3.4 That additional funding be made available to colleges and universities to provide the improved facilities and instruction necessary to permit adequate training in ground control.

3.5 That the mining industry shall establish a special chair in ground control at an Ontario university to improve the standard of teaching in rock mechanics for graduate and undergraduate students, and to conduct research projects directly related to the mining industry. This chair shall be closely identified with the Ontario mining industry, and shall take direction from the industry.

3.6 That instruction in ground control be integrated into the undergraduate programs in mining engineering. The Rock Mechanics and Strata Control Committee of the Canadian Institute of Mining and Metallurgy shall be asked to effect this change through the organization of a National Forum on mining-related ground control education.

3.7 That community colleges and universities offering mining programs be encouraged to develop additional short courses in ground control, targeted to specific groups in the mining industry.

3.8 That the mining industry in Ontario be encouraged to sponsor their employees' attendance at existing short courses and other programs as they become available.

3.9 That these short courses be designed so that adequate training can be given in various locations, including remote regions of the province.

3.10 That certification courses be developed in practical ground control for practising ground control engineers and other technical personnel.

3.11 That the mining industry be encouraged to sponsor qualified employees who seek post-graduate degrees in rock mechanics.

4. COMMUNICATIONS

FINDINGS AND CONCLUSIONS

The are two aspects to mine communications: the content, the information that is passed from one person or group to another; and the mechanism, the means — including mechanical devices like radios and telephones — by which this information is passed. The Committee finds that both need to be improved in Ontario mines.

The responsibility for communicating effectively, for ensuring that appropriate information is received and understood, rests with mine management. Management is also responsible for ensuring that adequate mechanisms exist to receive, evaluate and act on feedback from workers concerning hazards in the workplace, and methods of removing or reducing them.

The flow of information within the management group, from the management group to workers, among workers, and from workers to the management group is important. For example, information on geological structures that affect ground stability must be passed from geology department observers underground to ground control and mine engineering staff, to mine planners, to production staff, and to miners. In addition information based on observations made in the workplace must be shared with cross-shift workers, production staff and mine planners.

The effectiveness of communications in Ontario underground mines varies widely. In some cases formal procedures have been developed to encourage the flow of information; in other companies no formal structure exists, and the flow of information is impeded as a result.

Of particular importance is the incorporation of relevant data into mine production plans. It is a common observation that mine design is subject to constant modification as new information becomes known. Most of those modifications will have no effect on the stability of the ground, but some may have a very great effect. There is a need for better consultation between production engineers and ground control engineers to identify and correct the changes in design that alter ground stability.

The need for better mechanical devices to improve communications underground, and particularly for the development of better radio systems, has been noted by previous investigations of mine safety, and by coroners' juries investigating mine deaths. No standard for

underground communication systems yet exists, and the development of such a standard is an urgent priority. This Committee finds that there is a need for adequate radio communication systems in underground operations.

RECOMMENDATIONS

4.1 That companies reassess the effectiveness of their methods of providing information on ground control and emergency preparedness to employees.

4.2 That mining companies recognize that it is the responsibility of management to establish direct and effective communication between management and workers, and to ensure that adequate mechanisms exist for clear and timely feedback from workers to management.

4.3 That management should also ensure that mechanisms are in place to provide effective communication between workers on cross-shifts, and that these means of communication be available to both workers and supervisors.

4.4 That research to perfect the development of an effective radio communication device for use underground be continued and accelerated, with active government support.

4.5 That once developed and available these devices be installed in underground locations as necessary.

5. MINE DESIGN AND PLANNING

FINDINGS AND CONCLUSIONS

Mine design is critical to the success of any mining operation. Good, well-thought-out planning can ensure maximum safety, with minimum disruption to production. On the other hand, poor design can lead to serious local and regional stability problems.

Historically, mining techniques in Ontario mines and in other mines around the world have evolved in response to pragmatic concerns. Much of the mine design and planning was based on site-specific experience, with little rock mechanics input. In some instances this resulted in major stability problems. However, growing economic and safety concerns are directing companies to choose mining methods and to plan mines with due consideration for ground conditions.

With the advent over the last decade of sophisticated computer-assisted geotechnical design methods, it is now feasible to incorporate rock mechanics concerns into initial design, and thus minimize the potential for serious ground problems during production. Most of the Ontario mines that this Committee visited are now using these techniques for mine design. The Committee believes that this trend should be accelerated to encompass all future mine design. A minimum requirement should be that mine design be systematic, and that the basis for the design be well documented.

The increasing complexity of ground control techniques, and the advancing technology in the field, also demand that mine design, and the implementation of that design, be done under the direction of professionally-qualified individuals.

Section 5 of the Mining Regulations charges the Ministry of Labour with the responsibility for reviewing mine design and new mining methods prior to their implementation. It is the conclusion of this Committee that this review process must be expanded to include not only pre-development reviews, and review of proposed expansion of existing mines, but also routine reviews of ground conditions and practices in each Ontario mine at least once per year, and more frequently if required.

In addition to the measures taken by individual mines to ensure ground stability, it must also be remembered that mining operations on one side of a common boundary may affect stability and ground control on the other side of the boundary. Mining methods used in one mine may cause ground problems in its neighbour. In consequence, good ground control practices demand co-operation and sharing of

information among of all mines operating in a specific region, especially those operating on adjacent sides of a boundary pillar. Section 18 of the Mining Regulations already requires this exchange of information, but more complete and more timely exchanges are needed.

Finally, one of the union briefs presented to this Committee made a useful distinction between ground control problems that occur in the "micro-environment" — the area affecting one miner or group of miners working in a specific area — and those that occur in the "macro-environment" — the entire mine or a large portion of the mine. In the case of the "micro-environment," the miner is a good judge of ground conditions, and is able to take measures to improve them — by scaling loose to prevent falls of ground, for example. But the individual miner is powerless to improve ground conditions in the "macro-environment," which depend on such issues as mine design, geological conditions, and mining methods and sequences.

Ground conditions in the macro-environment are clearly the responsibility of management; however it makes good sense for management to communicate information about ground conditions and measures to ameliorate them to the workers as clearly as possible, and as frequently as necessary. It makes equally good sense for management to institute some formal mechanism to receive information from workers about the ground conditions in the micro-environment where they work, and to consider carefully the improvements and precautions suggested to deal with them.

RECOMMENDATIONS

5.1 That mine design continue to be recognized as the sole responsibility of management, and that management accept the need to use appropriate technology in designing mines.

5.2 That mine design and subsequent implementation be under the direction of a technically competent person.

5.3 That every underground mine be required to prepare a ground control macro-environment design prior to the introduction of a new mining method, or the introduction of any expansion of the present mine design; such designs shall be submitted to the Ministry of Labour as required by Section 5 of the Mining Regulations.

5.4 That technically competent personnel of the Ministry of Labour review ground control design and procedures at all Ontario mines, at the mine site, at least once per year, and more frequently as required.

5.5 That the principles and details underlying the mine designs referred to in Recommendation 5.3 be communicated directly to persons concerned at all levels of the operation, including the appropriate officials of the union representing the mine crews; and that this communication take place before and during the implementation of the design.

5.6 That the Ministry of Labour review and monitor the regional stability affecting underground mines in Ontario, and discuss potential problems with the mining companies involved.

5.7 That mining companies sharing a common boundary exchange information that may affect the regional stability of either or both.

5.8 That workplace mining plans be made available to miners and be discussed with them, including any indications of abnormal ground conditions, geological anomalies, and the location of ground monitoring instruments, as a method of ensuring worker participation in planning ground control procedures in the "micro" environment.

6. EMERGENCY PREPAREDNESS

FINDINGS AND CONCLUSIONS

Ontario's mine rescue organization was established in the early 1930s, following a tragic mine fire at the Hollinger Mine, and fire underground has remained one of the principal pre-occupations since that time. However the approximately 1000 volunteers who comprise the mine rescue teams are also competent in many other areas. The equipment and training of the mine rescue workers is under the direction of Mine Rescue Officers appointed by the Ministry of Labour, although all costs are borne by mining companies.

Fires are still the principal emergencies which mine rescue teams must face. In 1984 there were 93 fires reported, and mine rescue teams were called in to assist on 25 occasions. But the need for more diversified training and equipment became clear in 1980, when three miners died during a major rockfall at the Denison mine.

It was underlined in 1984, when it required 27 hours of heroic effort for rescue workers to traverse some 20 feet of fallen backfill and debris following the Falconbridge rockburst. There is a need for more suitable rescue equipment, to reduce the length of time rescue workers are imperiled, and to improve the chances of saving trapped men.

This Committee believes that the existing Ontario Mine Rescue organization is capable of dealing with non-fire emergencies. But the mine rescue organization must be expanded and improved. Better training in rescue and recovery operations related to non-fire emergencies is required, and there is a need to have specialized light-weight, portable equipment available for non-fire rescue operations. The mine rescue organization should attempt to identify the equipment required for this type of emergency, identify sources for this equipment, and determine where it should be available.

For example, mine rescue operations might be facilitated if rescue stations and sub-stations were equipped with devices specifically designed for reaching and extricating workers trapped by falls of ground, as well as special protective clothing, roof supports, electrical generators, cutting tools and ropes and stretchers.

There is also a need for improved first-aid emergency treatment equipment for use underground, for more extensive first-aid training for underground workers, and for up-graded training and better qualifications for first-aid attendants. Implicit in this is a requirement for changes in the Workers' Compensation Board regulations, which set requirements for first-aid. These regulations were written with surface plants in mind, and are inadequate for conditions in underground mines.

RECOMMENDATIONS

6.1 That the current mine rescue organization be expanded to handle all underground emergencies.

6.2 That the necessary additional training in non-fire emergencies be developed by a tripartite committee consisting of representatives of mine management, unions, and government.

6.3 That a tripartite committee also be established to advise on all aspects of mine rescue equipment and emergency warning systems.

6.4 That mine rescue personnel suffer no loss of income as a result of injuries arising from mine rescue activities.

6.5 That the Ministry of Labour mine rescue organization be responsible for identifying and introducing specialized equipment needed for use in non-fire emergencies, and for developing or finding sources for such equipment.

6.6 That manway sizes, escape routes and refuge stations be sufficient to accommodate rescue operations.

6.7 That the Workers' Compensation Board re-evaluate the qualifications required for mine first-aid attendants.

6.8 That all underground workers be encouraged to take first aid training, and to keep their training current.

6.9 That the Ministry of Labour, with the assistance of the Mining Legislative Review Committee, draft comprehensive first-aid regulations with specific reference to underground mining operations.

7. MINE LIGHTING

FINDINGS AND CONCLUSIONS

Poor lighting is rarely the primary cause of underground accidents, but it can be a contributing factor. So far as ground control is concerned, poor lighting makes it easy to miss dangerous conditions that could otherwise be corrected.

It should be noted that adequate lighting is not merely a question of enough light, but also a question of the right kind of light. Glare, shadows and colour affect a miner's ability to see cracks, seams or structures that indicate danger.

Attempts have been made in the past to establish lighting standards for use in underground mines. Despite these efforts no generally-accepted lighting standard exists. It is the finding of this Committee that improved underground lighting is needed. The development of underground mine lighting standards should also be given more priority.

RECOMMENDATIONS

7.1 That auxiliary high-intensity lighting be available in all active work areas to assist in ground-control-related activities such as inspection and scaling.

7.2 That within one year of the release of this report lighting standards — as they relate to ground control and emergency preparedness — shall be established for use in all underground mines.

8. MONITORING AND INSTRUMENTATION

FINDINGS AND CONCLUSIONS

Most of the mines in Ontario have installed some type of instrumentation to monitor rock movement and stresses. However the amount and quality of ground control monitoring varies widely from company to company.

A survey conducted for this Committee indicates that two-thirds of Canadian hardrock mines have either a rock mechanics department or an engineer with at least part-time responsibility for rock mechanics, and about 80% of those mines have installed some sort of instrumentation to monitor rock movement and stresses at some point during the life of the mine. By contrast, this is true of only 25 per cent of the remaining mines, those which have little or no on-site expertise in rock mechanics.

Similarly, computer modelling is done by about 70% of those mines which have a rock mechanics department; by about 50% of those mines which have assigned part-time responsibility for rock mechanics to an engineer; and by about 15% of the mines which have no formal on-site rock mechanics expertise. Those results are thought to be also indicative of the situation in Ontario mines.

In Canada, six mines where rockbursts have occurred have installed microseismic monitoring devices; five other mines plan to install them in the near future.

The instruments and the monitoring methods used range from simple home-made devices to indicate convergence in stopes to electronic microseismic monitoring systems that cost in excess of $400,000. However, regardless of the sophistication or simplicity of the instruments used, the purposes of monitoring ground conditions are the same:

a) To collect hard data to help explain and eventually predict ground control problems;
b) To provide ground control data for use in mine design and mine planning; and
c) To resolve disagreements about safety conditions and allay worker concern.

The present state of monitoring and instrumentation does not achieve these purposes, either in Ontario, or in mines around the world. There is no agreement on the interpretation of data from ground movement monitoring systems. And while microseismic monitoring systems have been very successful in identifying seismically active areas, they have not yet been successful in predicting rockbursts or falls of ground.

There is no standardization of monitoring techniques across the industry, and a consistent approach to the design of monitoring programs is needed. There is also a clear need for more economical instruments and monitoring methods. And there is a clear need for monitoring and testing programs to be incorporated into mine design and mine planning at the earliest stages, before ground control problems have become manifest.

RECOMMENDATIONS

8.1 That research into improved rock mechanics instrumentation of all types be undertaken.

8.2 That specific research to develop improved, reasonable-cost measuring devices be pursued.

8.3 That guidelines be developed for the interpretation of data produced by ground monitoring devices.

8.4 That all information obtained from ground monitoring devices at a particular mine be provided to the union representing workers in that mine.

8.5 That any evaluations of ground conditions in areas being mined shall be given to the union representing workers in each mine, and shall also be communicated directly to the workers involved.

8.6 That mines experiencing on-going rockbursting problems install instruments, such as micro-seismic monitoring devices, to monitor seismicity in the affected areas.

9. MISCELLANEOUS

FINDINGS AND CONCLUSIONS

Hard Rock and Soft Rock Mines. The Committee found that clear differences exist between hardrock underground mines and soft rock mines or open pit mines, and these differences must be recognized when regulations are made. Practices that may be desirable or even essential in hardrock mines may have no value in soft rock or open pit mines.

The Role of the Ministry of Labour. In general, this Committee recommends a more active role for the Ministry of Labour in respect of ground control and emergency preparedness. If the Mines Inspectors of the Ministry of Labour are to have a role in ground control they must be — and must be perceived to be — technically competent. Training programs similar to those taken by mining company personnel are desirable, and joint training might be considered.

The Committee views the Ministry as a potential source of technical expertise on rock mechanics and ground control; as a regulatory agency capable of enforcing compliance with regulations dealing with ground control and emergency preparedness measures; and as a co-ordinating body capable of undertaking province-wide or industry-wide programs. All of these roles are reflected in the recommendations directed to the Ministry.

Fall-On Protection Systems. The need for devices to protect workers operating equipment underground from falls of ground has been emphasized in several briefs submitted to this Committee and to previous inquiries into mine safety. Falls of ground are a continuing source of injuries and deaths in Ontario mines, and there is a perceived need to install devices on mechanical equipment to protect their operators from this hazard. However, further studies are required to determine appropriate standards for the installation of these devices in view of the wide variety of mechanized equipment used underground.

Worker-Inspectors. A number of mines in Ontario have negotiated the use of worker-inspectors, who are responsible for identifying hazards in the workplace and for drawing them to the attention of mine management. While the role of worker-inspectors was recognized, the Committee failed to reach any consensus on the question of legislation or regulation to enforce their use. The four Labour representatives on the Committee would recommend that legislation be introduced to require the use of worker-inspectors.

The Continuance of this Committee. Many previous inquiries and investigations into mine safety in Ontario have made recommendations similar to those made by this Committee. Several of those recommendations have never been implemented, and this Committee wishes to make some provision for monitoring the implementation of the recommendations embodied in this report.

RECOMMENDATIONS

SOFT ROCK MINES

9.1 That soft rock mining operations be considered separately from hardrock mining in setting standards related to ground control practices.

MINISTRY OF LABOUR

9.2 That the Ministry of Labour, through training and recruitment, ensure that its ground control staff be at a world-class level in their discipline, and have the credibility to relate effectively to the international ground control community.

9.3 That the Ministry of Labour establish a Technical Support Centre with the following functions:

a) to support an expanded role in pre-development review and annual mine design review as recommended elsewhere in this report;

b) to establish facilities for training in ground control (although this should not conflict with existing established training programs).

c) to develop, and provide to mines on short-term loan, ground control instruments and testing equipment;

d) to establish and maintain a computerized data base containing operational information on ground control and emergency preparedness and provide access to it to the mining industry, and to the research co-ordinating body recommended elsewhere in this report;

e) to develop and maintain a library of computer software related to ground control technology, and especially to the interpretation of data from ground control monitoring devices.

f) the specialist ground control engineers employed in the Technical Support Centre should not be involved in the regulatory functions of the Ministry.

g) the Technical Support Centre shall not be in conflict with the research co-ordinating body recommended elsewhere in this report.

9.4 That Ministry of Labour inspectors be provided with such additional training as may be required to enable them to deal effectively with site-specific ground control problems.

9.5 That these inspectors enforce ground control regulations more vigorously.

FALL-ON PROTECTION SYSTEMS

9.6 That Fall-On Protection shall be mandatory on all vehicles operating in areas requiring this type of protection. This recommendation shall be referred to the established FOPS sub-committee which will develop standards for its implementation.

WORKER INSPECTORS

9.7 That worker-inspectors, where they exist, be given the same training in ground control as that recommended for supervisory staff elsewhere in this report.

THIS COMMITTEE

9.8 That this Committee will remain seized with this study and will reconvene as necessary to discuss matters requiring further attention and to monitor progress on the implementation of these recommendations.

SECTION 5: Appendices and Reference Material

APPENDIX I: Examples of research projects undertaken by Ontario Mining Companies

A large number of mining companies in Ontario conduct substantial amounts of research. The following abbreviated descriptions of company-sponsored research are taken from the briefs submitted to the Committee.

ADAMS

"The various ground control programs in place at Adams Mine have been developed over the years with the assistance of Slope Stability Consultant Dr. P.N. Calder, P.Eng., who is currently Department Head, Mining Engineering Department, Queen's University. Dr. Calder makes annual visits to the Adams Mine to inspect pit walls and waste rock dumps, and makes recommendations regarding slope stability in the Adams Mine pits. Dr. Calder has been consulting at Adams mine since 1968."

ALGOMA

"During the 1960s, measurements were taken of the three principal stress directions underground; compressive strength tests made of siderite ore; studies made of pillar deformation using bolt and wire extensometers; sub-audible noises listened to with a Seismitron; and sonic velocity measurements in siderite. All this work was a co-operative effort between Algoma and the Department of Energy, Mines and Resources Mines Branch, Ministry Research Centre.

"Recently a microseismic unit with 7 geophones was installed on surface for a test period of one year."

"A McPhar rock stress monitor was tested underground in 1984 as part of a co-operative project between CANMET and McPhar Geophysics Ltd. The test wasn't successful…"

CAMPBELL RED LAKE

"Dr. Morrison was consulted on two occasions by Campbell to look at the problem associated with mining "A" zone. His first visit was 1961…"

"Mining 1102 E. 'B' stope through the level was a major problem.... In August 1981 we had the opportunity to show the 1102 sill to the Chief Ground Control Engineer in Ontario, Vic Pakalnis, the Mine Inspector and the Mining Engineer from Thunder Bay. Using their suggestions as a guide, a plan was formulated to destress the pillar. Dr. Wilson Blake, our consultant, was also asked to visit in February 1982."

"When it was decided to destress 1902 E. 'C' stope crown and sill pillars the microseismic system was operational. In addition to placing extensometer points to monitor closure, geophones were installed on levels above and below in the abutments."

"Numerical modelling at Campbell Mine has involved the use of both the finite element displacement discontinuity and boundary element techniques."

CANADIAN SALT

"In addition to the Company's own engineering staff, consultants are frequently retained to provide expertise in Geology and Rock Mechanics... Rock salt is a very plastic material. If subjected to any sustained load it tends to flow or creep as a means of stress relief. This behaviour is far different than that of the hard, brittle rock formations of Northern Ontario. As a result the dangers of sudden rock bursts are not a foremost concern in the 'soft rock' salt mine."

DENISON

"Much work has been done in the Elliot Lake area since mining was first started. The first major review of ground control practices in the area was carried out by the Special Committee on Mining Practices at Elliot Lake in 1958. As a follow-up to the recommendations of this Committee, more emphasis was placed on rock mechanics by Denison Mines, and studies were carried out mainly by Professor Emery of Queen's University, and although these were centered mainly around the use of photo-elastic gauges, attention was also placed on all other areas of ground control, including pillar size, rockbolting and visual monitoring."

"Since the Elliot Lake Laboratory of CANMET, Department of Energy, Mines and Resources, Canada was established in 1965 over 40 reports have been written on various aspects of rock mechanics in the Elliot Lake uranium mines."

"Pillar design is based on the determination of field stress and strength and evolving empirical criteria for pillar stability. As the mine is reaching greater depths, pillar sizing and extraction ratios have become very significant from an economic point of view. Pillar recovery operations are checked using computer simulation models based on displacement discontinuity concepts. Three models are used: MINSIM, which is an elastic solution with pillars incompressible; DZTAB model, in which pillars have a compressibility feature; and the NFOLD model, which has pillar failure criteria and variable dip features. Stress or safety factor contours can be graphically displayed and made available to planning for decision making."

DICKENSON

"A number of monitoring techniques have been tried on an experimental basis in this mine. These included various forms of convergence measurement, seismic velocity measurements, and the McPhar Stress Alert Ultrasonic Monitor. To date, few tangible benefits have been gained from the use of instrumentation, especially with respect to the problem of rockbursting...At present, "monitoring" consists of routine visual inspection of work areas by one person directly concerned with rock mechanics, as well as safety inspections and daily inspections by supervisors and the miners themselves. Pull-tests and torque-testing is done as required by the mining regulations to ensure quality control of support installations."

DOME

"The host rock at Dome is very competent and has not caused any serious ground problem or major rockbursts in the 75-year history of the mine.

"The objective of the earlier ground control programme at Dome was to monitor the size and the shape of a series of large open stopes which evolved from the original shrinkage mining methods...Presently a more sophisticated arrangement for monitoring ground movements has evolved. In place of the plumbing of old drill holes now a wire spring gauge is inserted into the drill hole under tension and is monitored from

a fixed head position at the collar of the hole...The accelerated rate of caving in certain stopes points to the necessity of attempting to increase our ability to predict the magnitude and the time of any future sloughing."

DOMTAR

"The new rock mechanics programme, initiated in 1975, adopted the time-control technique of the Stress Control Method to resolve the roof problem...A high degree of roof stability was obtained in the center, or 'protected', room roof which was excavated after the excavation of the two flanking 'control' rooms of this three-room experiment...Early data from the four-room entry made for this test also indicates the highly stable character of the two protected rooms, given this four-room geometry, in the Goderich A-2 mining level."

FALCONBRIDGE

"By the early 1960s, extensometers were being used to measure wall closures, photo-elastic discs to monitor stress changes in rock and support surfaces, and load cells to measure fill loads on support systems. In 1961 Falconbridge supported two graduate engineers to take master's degrees in rock mechanics at Queen's University...In 1970 Dr. K.H. Singh was hired as a rock mechanics specialist... Reporting to the Chief Rock Mechanics Engineer are a total of seven graduates, six of whom have post-graduate education, and eight technologists and technicians...A ground control department exists at each mining complex and typically consists of a ground control engineer and one to three technicians who are responsible for the field work involved in blasting and ground control."

"Computer modelling is generally used when mining plans for a stoping block or area are being assessed...At the present time we use a number of two-dimensional and three-dimensional programmes (NFOLD, FES2D, BEM2D, 3DBEM, DDJ2D, MINTAB). These programmes represent state of the art in computer modelling in the mining industry today. These programmes have been obtained from consulting and research organizations such as Golder Associates, CANMET, and the Commonwealth Scientific and Industrial Research Organization of Australia. Our geomechanics personnel are in regular contact with firms developing programmes to ensure that access to up-to-date programmes is maintained."

"Over the years, we have used a variety of monitoring instruments to check ground behaviour. Several of the instruments have been developed in-house in cooperation with our Instrumentation Department... The most frequently used instruments at the present time are: extensometers, ground movement monitors, load cells, earth pressure cells, pressure gauges, stressmeters and sloughmeters... A microseismic monitoring system (Electrolab 250 MP) was purchased for the Falconbridge Mine in 1980 and was installed by mid-1981."

GECO

"Rock mechanics studies have on a regular basis been undertaken at Geco since its inception and include:

a) geological interpretation of strata
b) systematic observation and plotting of cracking, sloughing and caving
c) measurements of deformation in drifts and cross cuts and correlation of observed movements with stoping
d) measurement of ground movement in a horizontal or vertical plane at selected sites with multi-wire extensometer techniques.

Data acquired is used to predict and coordinate future development mining, sequencing, filling and support activities."

INCO

"We began experiencing rock bursts in our mines in the late 1920s. The mining methods in those days were primitive; but, on the other hand, most activities, by today's standards, were primitive, and mining was no exception. By 1930, we had experienced three rock bursts, all at Frood."

"In the 70s, after evaluating the best models internationally available, and after consulting with experts and with CANMET, it became apparent that the available models did not meet our conditions, and, in 1979, we undertook a joint programme with CANMET for the development of a suitable three dimensional programme... Our objective is 'to develop a model that an average engineer without specialized knowledge of numerical modelling can use to determine the best mining geometry, mining sequence, and support system for any orebody, from beginning to end of mining'... We have been working for three years on this, and we estimate two more years are required to develop the preliminary working model. The computing power required

boggles the mind. If you have a computer capable of handling 20 million floating point multiplications per second it will take two weeks of continuous operation to complete one run. It is a very ambitious project but I believe that, if successful, it will solve most of our design problems."

KIDD CREEK

"To understand rock burst phenomena rock mechanics studies have been carried out in the mine, including *in situ* field stress and physical properties of rock, monitoring of abutment stress changes due to stope excavation and backfilling, and microseismic monitoring. Data obtained from those studies have been incorporated in mine planning to design an optimal mining method and sequencing."

"A SINCO MS-2 Geomonitor has been used in the mine for monitoring and recording underground seismicity for the past five years."

MACASSA

"Seismic velocity surveys were initiated in the latter part of 1982 and have been carried out on a regular basis since. To date over 60 surveys have been conducted."

"A recent agreement has been made with Falconbridge Ltd. whereby they will have the use of our spare seismic equipment. In return, they will make available to us any new techniques, findings or refinements to the present system. It is hoped that with their large ground control staff they might develop different inroads into this area of seismic research that would otherwise not be developed here, at Macassa."

NORANDA

"In the geomechanics area, one of the most forbidding technical problems is modelling the interaction between a mineralogically and structurally complex rock mass, geometrically complex underground mine excavation and their interaction with support systems. The collection of historical data on ground movement, pillar and support system performance, etc., from a variety of cases provides a fundamental data base to use in evaluation of the relative performance of various mining methods, support system, etc., under varying ground conditions. Numerical models provide the first truly effective tool capable of realistic back analysis of mine behaviour."

"At present, the geomechanics group has research programmes ongoing in the following areas:

a) microseismic monitoring and rockburst prediction
b) novel ground control instrumentation
c) mine excavation design theory
d) numerical modelling technology
e) mining ground control classification systems
f) *in situ* mining of copper oxide deposits, and
g) new mining methods.

The research efforts of the Mining Technology Division represent a very strong, long-term goal by Noranda to improved mine safety, planning and design."

RIO ALGOM

"In 1978, an Elliot Lake Rock Mechanics Group was set up with Rio Algom Limited, Denison Mines Limited and CANMET. The group was originally responsible for conducting the Elliot Lake regional stability studies through computer simulation. Having formulated the guidelines for mining along the property boundaries, the group is now involved in reviewing and exchange of pertinent information through regular monthly meetings between Rio Algom and Denison which are also attended by their respective unions. This was the first such group set up in Canada."

"Both Rio Algom and Denison Mines cooperated with the Mining Research Laboratory of CANMET since its establishment in Eliiot Lake in 1965, on basic and applied research. One of the first areas investigated was pillar design and it included:

a) measurement of the field and pillar stress at Nordic and Denison mines
b) laboratory tests of rock cores to define strength
c) compilation of the tectonic loading history of the Elliot Lake area
d) survey of failed and stable pillars in all the mines.

The result of this research was the publication of empirical pillar design guidelines in 1972 (Hedley and Grant), and which was updated to include multi-seam mining at Elliot Lake, in 1978 (Hedley). These guidelines were useful in designing recent stopes which included substantially larger pillars."

APPENDIX II: Summary of SRK/Golder Report on Mining in Canada

GENERAL BACKGROUND

Mines vary considerably in size, age, mining methods, depth of mining and rock conditions, and each of these factors affects ground control. Mine size tends to determine the resources and personnel devoted to rock mechanics and ground control; mining methods and rock conditions tend to determine the kind of ground control problems encountered; mine depth and age affect the seriousness and extent of ground control hazards because the effects of discontinuities and stress change with increasing depth in a mine, and older mines tend to have a high proportion of ore already removed, and so may be subject to rockbursting.

This Committee commissioned a technical study of the experience of hardrock mines in Canada and overseas with respect to ground control and rock mechanics, in an attempt to identify common problems and patterns of occurrences. Underground mines were classified according to mining methods, depth and size, and asked to respond to a questionnaire describing mining methods, ground conditions, and the staff and resources devoted to ground control. While the results reflect the existing situation in Canada, rather than Ontario, they are believed to portray accurately provincial as well as national conditions.

To simplify comparisons, four mining methods were selected as representing most Canadian mines, and all others were considered as variations of these four:

- **open stoping,** including blasthole stoping, long hole stoping, sublevel open stoping, vertical retreat mining, mass blasting, AVOCA, and VCR mining methods.
- **cut and fill,** including overhand cut and fill, undercut and fill, and shrinkage mining methods;
- **caving,** including block caving and sublevel caving;
- **room and pillar,** including conventional room and pillar methods and longwall mining methods.

Canadian hardrock mines were also classified according to size, as determined by the tonnage hoisted:

- **less than 200 tons per day.** These mines were considered unlikely to have professional rock mechanics engineers on staff, and to rely mainly on the experience of miners and supervisors;
- **200 to 2000 tons per day.** These mines may or may not have input from professional rock mechanics engineers, either on staff or as consultants; the use of professional rock mechanics advisers depends largely on management attitudes.
- **more than 2000 tons per day.** These mines probably have in-house ground control staff and probably engage outside consultants as required.

The mines were also classified according to depth:

- **less than 250 metres.** At this level geological structure is very important, there is little confinement, but falls of ground due to geological structure are more likely to occur.
- **250 to 1000 metres.** Geological structure becomes less dominant (except as a control of rock mass strength) and in situ stress becomes more important.
- **more than 1000 metres.** Stress becomes of primary importance, rockbursts become more prevalent.

Some 65 hardrock mines, representing most of the Canadian mines operating at the time of the survey, responded to the questionnaire. The mining methods used and the amount of tonnage produced are summarized in table 2 and table 3.

There are some anomalies apparent from these figures. Seven mines using room and pillar methods produce 30,000 tons of ore per day, or about 4000 tons/day per mine, the highest level of production of any method. This category is dominated by the uranium mines in the Elliot Lake district. The production from the open stoping method is dominated by medium to high producing mines operating at depths between 250 and 1000 metres. Most of the mines using cut and fill operate at medium production rates and at depths between 250 and 1000 metres. The charts on the following pages show the relationships between depths and production rates for each of the mining methods.

It would be convenient if ground control problems sorted themselves into neat categories that could be assigned to specific types of mining operations at specific depths. Unfortunately reality is

TABLE 2. MINING METHODS

(65 Canadian Hardrock Mines)

Method	Number of Mines
Open Stoping	31
Cut and Fill	23
Caving	4
Room and Pillar	7
	65

TABLE 3. TOTAL PRODUCTION BY MINING METHOD

(65 Canadian Hardrock Mines)

Method	Tonnage/day
Open Stoping	95,000
Cut and Fill	50,000
Caving	10,000
Room and Pillar	30,000
	185,000

less tidy than that. The results of the technical study demonstrate few clear trends in the types of problems being encountered in comparison with production rates and mining depths. It is known that significant stress problems will invariably develop at great depths, and/or where high extraction ratios exist over extended areas of the mine. The Committee's survey shows increased stress and seismic problems do occur with depth, but not all mines are equally affected. Dome Mines in Timmins, for example, is mining at a depth of over 1500 metres, using the cut-and-fill method, and experiences few stress-related problems in the stopes, and essentially no seismic events. By contrast, Rio Algom's Quirke Mine began experiencing rockbursts at a depth of approximately 500 metres. In this case the relatively high extraction ratios and the extensive areas mined are much more critical than the depth of mining.

FIGURE 4. NUMBER OF MINES USING OPEN STOPING MINING METHOD

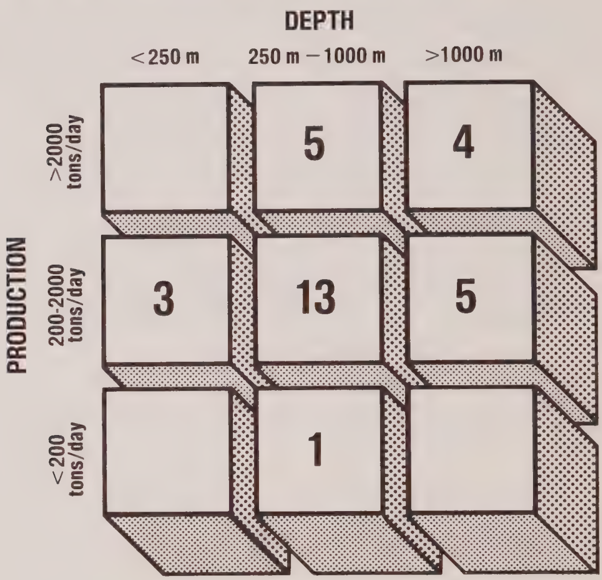


FIGURE 5. NUMBER OF MINES USING CUT AND FILL MINING METHOD

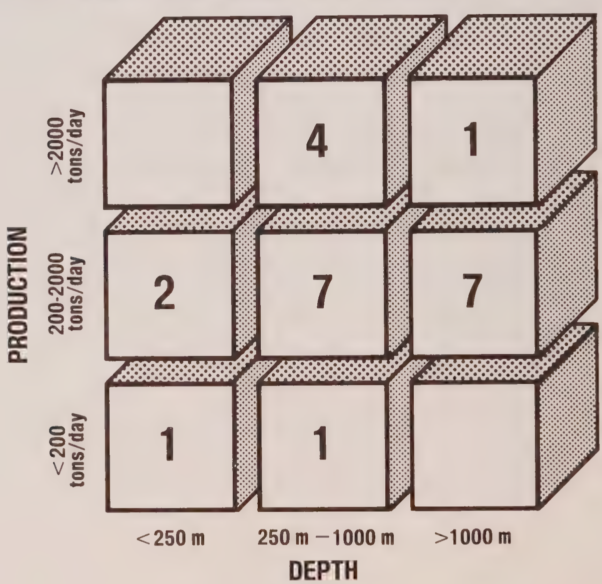


FIGURE 6. NUMBER OF MINES USING CAVING MINING METHOD

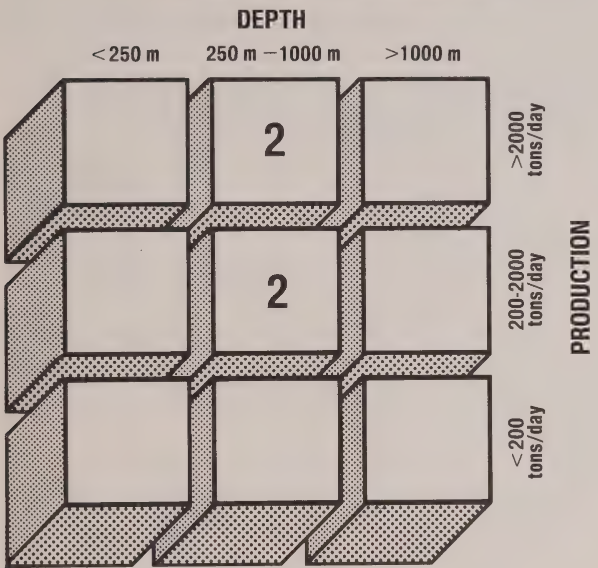
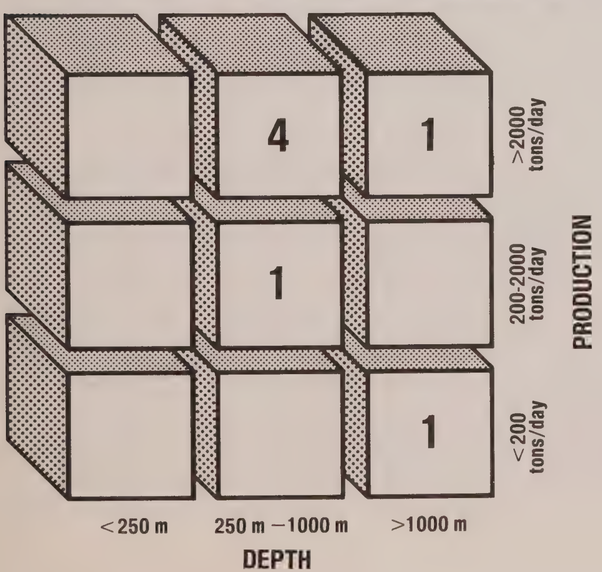


FIGURE 7. NUMBER OF MINES USING ROOM AND PILLAR MINING METHOD



USE OF ROCK MECHANICS PERSONNEL IN CANADIAN MINES

The results of the technical study show a definite pattern in the use of professional engineers with expertise in rock mechanics. The 65 Canadian hard rock mines which responded to the questionnaire can be divided into thirds: about one third have a rock mechanics department with at least one full-time engineer; one third have an engineer who spends at least some time on rock mechanics and ground control; and one third have no engineer specifically responsible for rock mechanics at the mine.

In general, the degree of involvement with rock mechanics is proportional to the size of the mine, although there are many exceptions to that statement. Larger mines tend to have more resources available to deal with ground control problems, and because they tend to be older and deeper mines, they also tend to have more ground control problems to deal with.

In the one third of mines with a separate rock mechanics department, that department ranges in size from one engineer with one or two years' experience to nine engineers (with three to 12 years' experience) and seven technicians. The level of formal training ranges from graduate engineers with no post-graduate training to those with doctorates.

For the one third of mines with one engineer who spends some time on rock mechanics, the amount of time devoted to this subject varies from as little as five per cent to as much as 60 per cent. The one third of mines which have essentially no specific rock mechanics function generally have relatively good ground, and operate at a low rate of production.

As might be expected, the mines with rock mechanics departments tend to have a strong sense of the importance of rock mechanics, not only in terms of safety, but as a means of increasing productivity and reducing costs. In mines where rock mechanics is part of the responsibility of an engineer, most emphasis is placed on rock mechanics in relation to mine safety.

These two groups of mines — which comprise approximately two thirds of the total — also make extensive use of outside consultants and specialists; about 75 per cent of these mines use independent consultants, and about 50 per cent have used the services of a government or university research facility at some point in the life of the mine. By comparison, about 50 per cent of the mines with no on-site

rock mechanics expertise use outside consultants, and very few of these have ever consulted an outside research facility. Table 4 summarizes these findings.

TABLE 4. ROCK MECHANICS PROGRAMMES IN CANADIAN HARDROCK MINES

Rock Mechanics Personnel	Characteristics
Separate rock mechanics dept. (One-third of mines, generally larger operations)	■ annual spending on rock mechanics \$100,000 - \$300,000 per year per mine ■ separate rock mechanics department; 1 - 9 full-time engineers with technical support staff. ■ high proportion of mines with "entry" type mining methods. ■ use rock mechanics to increase productivity and minimize costs, as well as improve safety only. ■ about 75% of mines use independent consultants; about 50% have used government or university research facility
One engineer with part-time responsibility for rock mechanics (One third of mines)	■ time devoted to rock mechanics varies from 5 - 60%. ■ rock mechanics used for safety only. ■ about 75% use outside consultants; frequent use of head-office expertise in rock mechanics. ■ annual spending on rock mechanics \$30,000 - \$100,000 per year.
No on-site expertise in rock mechanics	■ usually low production in "good" rock. ■ annual spending less than \$40,000 on rock mechanics and ground control. ■ typically consider rock mechanics as safety-related only. ■ about 50% of mines use outside consultants; rarely or never use government or university research facilities.

The attitude of mining companies towards rock mechanics, and the amount of money devoted to it also vary with the size of the mine. In many of the mines with rock mechanics departments, the application of the technology is viewed not only as a necessary part of maintaining safe mining conditions, but also as a way to optimize production and minimize costs. Rock mechanics and sophisticated ground control techniques are seen as ways of developing "cheap" ore — for example, by reducing ore dilution through the adoption of the stope and pillar sizes best suited to the existing rock conditions.

However many other mines regard rock mechanics only as a method of improving the safety of mine conditions, and as important as

safety is, this attitude has fostered the concept of rock mechanics as a service function, like surveying or computing, and like them secondary to the main business of the mine, which is getting the ore out of the ground. In turn this has hindered the integration of rock mechanics into overall mine operation and mine design. The net result is that in mines with a "safety only" concept of rock mechanics the function is not given full importance.

Not surprisingly, the amount of money devoted to rock mechanics also depends on both the size of the mine and the attitude toward the function. As a very crude approximation (necessary because spending varies very widely) in mines with a specific rock mechanics department, annual spending is approximately $100,000 to $300,000 per mine per year. Mines with on-site engineers who count rock mechanics as one of their responsibilities spend between $30,000 and $100,000 per year. Mines with little or no on-site expertise in rock mechanics spend less than $40,000 per year. Those figures include salaries, instrumentation, computer modelling, outside consultants, testing and evaluation, research and education — in short everything except the hardware used to support the rock.

The level of education and training of individual staff members is generally satisfactory. In particular, a significant number of employees in rock mechanics departments have post-graduate training in this field.

APPENDIX III: Report on the Rockburst at the Falconbridge Mine, June 20, 1984

INTRODUCTION

On June 20, 1984, beginning at 10:12 a.m., a series of large seismic events, up to a Richter 3.4 magnitude, occurred in the vicinity of the 4025 level of Falconbridge No. 5 Shaft and the 4200 level of the adjacent No. 9 shaft. This resulted in significant damage in a stoping area on the 4025 level and major failure of the drift support timber on the 4200 level. Substantial damage occurred also on the 3600 and 4300 levels.

The timber mat and fill in a stope back on the 4025 level collapsed trapping four men who were in the stope at the time. Three of the trapped men died instantly while the fourth, trapped between the bottom plate of a Cavo loader and wire mesh and collapsed cemented fill, survived until moments before his release by the rescue crew at approximately 12:45 p.m. on June 21.

Seismic activity continued throughout the rescue operation and, on several occasions, forced the retreat of the rescue team to safer ground.

RESCUE ATTEMPT

A rescue attempt was organized on the 4025 level immediately after the 10:12 a.m. rockburst and, under the direction of the mine shift boss, made attempts to establish contact with the men in the collapsed stope until a retreat was forced by continuing rockbursting and ground movement. A second attempt was made to gain access to the stope through both entrances at about 10:45 a.m. when the Underground Superintendent arrived on the level and voice contact was made with one of the trapped men. Rescue attempts were started then at both stope entrances with a total crew of 14 men. A major rockburst at 12:10 a.m. forced the rescue crew to retreat to safety. The rescue operation was resumed at approximately 4:00 p.m. when the seismic activity decreased to acceptable levels.

MINE EVACUATION

Stench gas was injected into the compressed air line at 10:20 a.m. to alert underground personnel of the emergency and advise them to proceed to refuge stations. A check of personnel underground was completed by 11:30 a.m. and accounted for all men except the four

who had been in the caved stope. The decision to evacuate the mine was made when the 14-man rescue crew returned to the refuge station.

Men working in Falconbridge Mine in #5 Shaft area were hoisted to surface by 12:34 p.m. Failure of the power supply to the #9 shaft hoist at the time of the 12:10 rockburst forced evacuation of men below the 4025 level through East Mine. All employees underground, except the four trapped men, were accounted for or on surface by 4:20 p.m.

MINE RESCUE ORGANIZATION

From the numerous trained volunteers, six mine rescue teams were formed, each consisting of eight men and a supervisor. Because it was agreed that booms and square sets would have to be used to reach the trapped men, each team included at least one man with extensive square set mining experience and one miner experienced in standing support timber.

The teams were scheduled to work four hours in each 24-hour period and were relieved at the rescue site by the next nine-man team. The rotating team captains discussed conditions and progress at the site permitting the rescue effort to continue without stop. The entire team participated in a detailed debriefing session, which was recorded, on arrival on surface after their shift.

A telephone line was installed near the rescue operation and contact was maintained with the rescue team at all times.

MEDICAL AND FIRST-AID COVERAGE

The company first aid supervisor and medical director arrived at the mine at 10:46 a.m. on June 20th and proceeded underground where they accompanied the first rescue team until forced to retreat by the second major rockburst. They returned to the rescue site when the mine rescue operation resumed, remaining until the operation was completed.

A first-aid attendant and ambulance remained at the mine site throughout the operation.

UNION INVOLVEMENT

The President and Union Chairman of the Safety and Health Committee of Local 598 of the MIne, Mill and Smelter Workers Union and the Chairman of the Office, Clerical and Technical Union Safety and Health Committee (USWA) were advised of the rockburst and arrived at the

mine at about 11:00 a.m. Union officials were present at rescue central headquarters throughout the rescue operation. Three members of the Falconbridge Mine Safety and Health Committee were involved as rescue team members.

PRESS MANAGEMENT AND EMERGENCY NOTIFICATION PROCEDURES

Company and Union Officials held the first press conference at 3:00 p.m. on June 20th. The media personnel were advised that regular pre-scheduled press conferences would continue throughout the rescue operations and that they would be advised of any major developments. A standard notification procedure is in place at Sudbury Operations and families were contacted in person and regular contact established and maintained throughout the ordeal. The names of the trapped men were not released publicly until their recovery and authorization was received from their families.

TOOLS, EQUIPMENT AND AVAILABILITY OF MATERIALS

Standard mine rescue emergency equipment was maintained at the mine site. Due to the confined space during rescue operations, rescuers used axes, hammers, saws, knives, pliers, etc. as emergency equipment. The warehouse and tool crib were manned and open during the rescue operation to ensure that whatever was needed underground would be sent without delay.

ROLE OF MICROSEISMIC MONITORING

A surface seismograph and a microseismic monitoring system had previously been installed at the Mine. These instruments were monitored on a 24-hour basis and rescue crews were debriefed regularly on the number and location of seismic events. Regular contact between the rescue crews underground and the microseismic monitoring station on surface was maintained via a telephone line.

CONCLUSIONS

A number of important factors were identified as being essential for future non-fire type emergencies involving rescue of trapped men.

1 Knowledge of timbering skills is essential and every effort should be made to ensure that some expertise is available in this area within each mining camp.

2. A non-fire emergency evacuation plan should be established at each mine.
3. Detailed debriefing sessions should be conducted with mine rescue teams and recorded.
4. Microseismic monitoring equipment can be extremely valuable during rescue operations in rockburst prone mines because it can accurately locate seismic events and alert rescue teams to an emergency.
5. A surface team, comprising both management and union personnel, should be established during a rescue operation to direct the crews and deal with the media, government and families of the trapped men.

APPENDIX IV: Submissions to the Committee

The following organizations and/or individuals made written submissions to the Committee:

- Denison Mines Ltd.
- Rio Algom Limited
- Noranda Mines Ltd.
- Campbell Red Lake
- Dickenson Mines
- Dome Mines Ltd.
- Domtar Chemicals
- Kidd Creek
- Lac Minerals Ltd.
- Inco Limited
- Falconbridge Ltd.
- Algoma Steel Corp.
- Canadian Salt Co.
- Ontario Mining Association
- Mines Accident Prevention Association of Ontario
- Mine Mill & Smelter Workers Union — Local 598
- United Steelworkers of America — District #6
- United Steelworkers of America — Local 6500
- United Steelworkers of America — Local 5762
- United Steelworkers of America — Local 5980
- United Steelworkers of America — Local 950
- United Steelworkers of America — Local 5417
- United Steelworkers of America — Local 7580

CANMET (The Canadian Centre for Mineral & Energy Technology)

Cambrian College

Laurentian University

McGill University

Queen's University

Dupont Canada Inc.

V. De Krompay

S.R. Weir (Enterprises Incorporated)

Ontario Ministry of Labour (Mining Health & Safety Branch)

APPENDIX V: Mine Visits and Hearings

The following is a list of the organizations visited by the Committee:

	Date of Visit
Falconbridge Mine #5 Shaft — Sudbury	Dec. 17, 1984
Falconbridge Strathcona Mine — Sudbury	Dec. 18, 1984
Inco — Creighton Mine — Sudbury	Dec. 19, 1984
Inco — Copper Cliff North Mine — Sudbury	Dec. 20, 1984
Inco — Stobie Mine — Sudbury	Dec. 20, 1984
Denison Mines Ltd. — Elliot Lake	Jan. 21, 1985
Rio Algom — Quirke Mine — Elliot Lake	Jan. 22, 1985
CANMET — Elliot Lake Facilities	Jan. 23, 1985
Domtar Chemicals (Sifto Salt) — Goderich	Jan. 24, 1985
Campbell Red Lake Mines — Balmertown	Jan. 28, 1985
Dickenson Mines — Balmertown	Jan. 29, 1985
Noranda — Geco Mine — Manitouwadge	Jan. 30, 1985
Dome Mines — Timmins	Jan. 31, 1985
Kidd Creek — Timmins	Feb. 1, 1985
Lac Minerals — Lakeshore Mine — Kirkland Lake	Feb. 12, 1985
Falconbridge Lockerby Mine	Feb. 14, 1985

The following is a list of briefs and commissioned reports heard by the Committee (location of hearing shown in brackets):

	Date of Hearing
United Steelworkers of America — Locals 5417, 5980 & 5762 — (Elliot Lake)	Feb. 26, 1985
Denison Mines Ltd. (Elliot Lake)	Feb. 27, 1985
Rio Algom Ltd. (Elliot Lake)	Feb. 27, 1985
Mine Mill & Smelter Workers — Local 598 (Sudbury)	Feb. 28, 1985
Falconbridge Ltd. (Sudbury)	Feb. 28, 1985
E. Legault re Belmoral Mines & CATAMINE (Sudbury)	Mar. 1, 1985
Noranda Mines Ltd. (Sudbury)	Mar. 11, 1985
Dr. E. Hoek — Report on Status of Colleges & Universities in Ontario (Sudbury)	Mar. 12, 1985

Mines Accident Prevention Association of Ontario (Sudbury)	Mar. 13, 1985
United Steelworkers of America — Locals 6500, 4584 & 4440 (Sudbury)	Mar. 15, 1985
United Steelworkers of America — District #6 (Sudbury)	Mar. 15, 1985
CANMET (Sudbury)	Mar. 25, 1985
Dr. Wilson Blake re Ground Control in USA (Sudbury)	Mar. 25, 1985
David Ortlepp re Ground Control in South Africa (Sudbury)	Mar. 25, 1985
SRK/Golders — Report on Ground Control in Canada & around the world (Sudbury)	Mar. 28, 1985
Ontario Ministry of Labour (Mine Health & Safety Branch) (Sudbury)	Apr. 9, 1985
Inco Ltd. (Sudbury)	Apr. 10, 1985
United Steelworkers of America — Locals 905, 7879 & 8126 (Thunder Bay)	Apr. 11, 1985
Dr. Malcolm Scoble re Status of Colleges & Universities in Canada (Sudbury)	Apr. 12, 1985
Ontario Mining Association (Toronto)	May 7, 1985
Ed Hollop — US Bureau of Mines (Toronto)	May 8, 1985
R. Peluso & J. Kravitz — US Dept. of Labour — Mine Safety & Health Division (Toronto)	May 9, 1985

APPENDIX VI: Glossary of Terms

Anfo — Ammonium nitrate. Fuel oil blasting agent.

Avoca — Mining method, also known as Cut-and-fill Rill Mining. A bulk mining method utilizing two sub-level developments, some 30 to 80 feet apart. Broken ore is withdrawn from below, rockfill material is introduced from above to fill the void.

Abutment — a surface or mass provided to carry large regional loads, for example the end supports of an arch or bridge or abutment pillars on either side of a stoping block.

Advancing Face — the wall of an opening that is being drilled and blasted.

Airbags — inflatable rubber device, used to lift heavy objects.

Applied Load — weight on a structure exerted by an external force.

Barring Down — removing, with a scaling bar, loose rock from the sides and roof of mine workings. Prying off loose rock after blasting, to prevent danger of fall.

Back — the ceiling of an underground working place.

Backfill — Waste sand or rock cemented or uncemented used either for support or to fill voids underground.

Bedrock — solid rock forming the earth's crust, sometimes covered by overburden of sand, clay or water.

Blasting — the operation of breaking ore or rock by boring a hole in it, inserting an explosive charge and detonating it.

Blasthole Stoping — bulk mining method using large diameter drill holes six inches to 15 inches in diameter, usually extracting a mining block of typical dimensions of 40′ wide x 100′ high. Depends on undercutting and overcutting the mining block and retreat blasting from a vertical face. The subsequent cavity is backfilled.

Blocking — a short piece of timber placed between the mine roof and the cap of a timber set and directly over the cap support. A wedge driven between the roof and the timber holds the set in place.

Block Caving — a method of caving in which a thick block of ore is partly cut off from surrounding blocks by a series of drifts, one above the other, or by boundary shrinkage stopes; it is then undercut by removing a slice of ore or a series of slices separated by small pillars underneath the block. The isolated, unsupported block of ore breaks and caves under its own weight. The broken ore is drawn off from below and as the caved mass moves downward, due to continued drawing of broken ore from below, it is broken further by pressure and attrition. The overlying capping caves and follows the broken ore downward.

Borehole — a hole made in the rock with a diamond drill or precussion drill, may be used for installing explosives or for rockbolts or to extract core for exploration.

Boundary Element Method — a form of computer analysis, where the boundary of an opening is divided into small segments and applied loads are calculated for each element in order to determine how the opening will behave.

Boxhole — some mining methods, such as shrinkage stoping, extract ore from the stope via mill holes that lead in some portion through rock to a level below. That portion in the rock is a boxhole.

Bulkheads — a) a tight partition of wood, rock and mud or concrete in mines for protection against gas, fire and water.
b) A wall or partition erected to resist ground or water pressure.

Cap Lamps — term generally applied to the lamps which a miner wears on his safety hat or cap. Used for illumination.

Cable Bolting — method of ground support where stranded cable is cemented in a borehole to reinforce the rock.

Caving — a mining method in which the ore is broken by induced caving. This may be achieved by (1) block caving, including caving to main levels and caving to chutes or branched raises; or (2) sub-level caving.

Cemented Tailings Fill — a combination of finely ground waste rock and cement used to backfill openings underground. The purpose is to support the walls of openings; or to provide a working floor.

Cemented Rockfill — same as above only using rock instead of tailings.

Computer Simulations — theoretical model of a portion of a mine programmed into a computer in order to predict ground behaviour.

Concurrent Backfilling — backfill that is placed in an underground opening immediately upon removal of the ore or rock.

Confinement — the use of some kind of support to prevent the expansion or deterioration of rock.

Continuous Miner — a mining machine designed to remove ore from the face and to load that ore into cars or conveyors without the use of cutting machines, drills or explosives.

Convergence — when ore is extracted the roof lowers and the floor lifts causing a convergence of roof and floor, with consequence loss of height.

Conveyorway — an excavation for a conveyor for the handling of materials.

Core Samples — one or several pieces of whole or split parts of core selected as a sample for analysis or assay.

Cribs — a structure composed of frames of timber laid horizontally upon one another, or of timbers built-up as in the walls of a log cabin. Used in ground support.

Crown Pillar — a horizontal plug of rock left above mined out opening for support.

Cut-and-fill — a method of stoping in which ore is removed in slices, or lifts, following which the excavation is filled with rock or other waste material known as backfill, before the subsequent slice is mined; the backfill supports the walls of the stope, and acts as a working floor.

Development Drifts — a main tunnel driven from the surface, or from a point underground to gain acess to ore prior to stoping operations.

Destressing — in deep mining, relief of pressure on abutments of excavation. Performed by drilling and blasting into the highly stressed rock to loosen the zones of peak stress. The peak load surrounding the stope walls is thus transferred deeper into the undisturbed rock, and a protective barrier is formed.

Dyke — a long and relatively thin body of igneous rock that, while in the molten state, has intruded a fissure in older rocks and solidified.

Dilution — the contamination of ore with barren wall rock during stoping operations.

Discing — the fracturing of a drill core into doughnut shapes indicative of high stress in the rock.

Discontinuities — an abrupt change in the physical properties of adjacent materials in any rock structures.

Displacement — a general term for the change in position of any point on one side of a fracture plane relative to any corresponding point on the opposite side of the fault plane.

Door Stoppers — type of stress measurement gauge installed in a borehole for determining in situ field stress levels.

Drawpoint — a spot where gravity-fed ore from a higher level is loaded into trucks or rail cars.

Drifts — a horizontal passage underground that follows along the length or parallel to a vein or rock formation as opposed to a crosscut which crosses the rock formation.

Earthquakes — a local trembling, shaking, undulating, or sudden shock of the surface of the earth, sometimes accompanied by fissuring or by permanent change of level caused by tectonic forces. Earthquakes are most common in volcanic regions, but often occur elsewhere.

Elastic — capable of sustaining stress without permanent deformation; the term is also used to denote conformity to the law of stress/strain proportionality.

Elastic Limit — of rock, yield point; maximum stress from which it can recover apparently unchanged. If stressed beyond this point there is disruption or permanent deformation.

Electric Blasting Caps — a device for detonating charges of explosives electrically. It consists generally of a blasting cap, into the charge of which a thin platinum wire is stretched across two protruding copper wires, the whole fastened in place by a composition sulphur plug. The heating of the platinum wire bridge by the electric current ignites the explosive charge in the cap, which in turn detonates the high explosive.

Empirical Observation — relying on or proceeding on the information derived from experience and observation for lack of other knowledge. Proceeding experimentally or by the trial and error method.

Entry — an underground passage used for haulage or ventilation, or as a manway.

Entry Type Mining Method — type of stoping method which requires miners to work in the opening.

Epi-Centre — point on the earth's surface directly above the focus of an earthquake. In rockbursting terminology, commonly used to indicate the origin of the seismic disturbances.

Excavation — digging, blasting, breaking and loading of ore or rock in mines.

Excavation Sequences — order in which nearby openings are made in order to control stress distribution.

Extensometers — instruments used for measuring small deformations, deflections, or displacements in rock.

Extraction Ratio — ratio of the mined area to the total area.

Face — as applied to a drift, crosscut or stope, is the end in which work is progressing.

Failure Zones — that portion of rock around an opening subject to collapse or movement.

Falls of Ground — in an underground mine, rock falling from the roof or wall, due to gravity into a mine.

Faults — a fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture.

Faulting — the movement which produces relative displacement of adjacent rock masses along a fracture.

Finite Element Analysis — computer modelling method whereby the rock and rock structures are modelled using small discrete elements.

Folding — the folding or bending of strata is usually the result of compression that causes the formation of the geologic structures known as anticlines, synclines, monoclines, isoclines, etc.

Footwall — in an inclined orebody the lower contact of the ore is called the footwall.

Fracture Zone — a mass or rock cut by many small irregular fractures.

Geological Structure — the disposition of the rock formations, that is, the broad dips, folds, faults and unconformities at depth.

Geophones — electronic sensing devices used to pick up seismic or microseismic emissions.

Gravity Induced Instability — fall of loosened rock caused by the gravitational pull.

Ground Control — application of rock mechanics, soil mechanics geological principles, and principles of strength of materials in getting the ore out safely and economically.

Gunite — a mixture of sand and cement, sprayed with a pressure gun onto roofs and ribs to stabilize rock surfaces.

Hanging Wall — in an inclined orebody the upper contact of the ore is called the hanging wall.

Heading — a passage leading from the gangway. A smaller excavation driven in advance of the full-size section; it may also be driven laterally, and is then called a cross-heading or side drift. A heading may be driven at the top or the bottom of the full-size face; it is then a top or a bottom heading as the case may be.

Horizon — any given definite position or interval in the stratigraphic column.

Hydraulic Backfill — waste material transported underground and flushed into place by use of water.

Hydraulic Fracturing — a general term, for which there are numerous trade or service names, for the fracturing of rock by pumping a fluid under high pressure into the rock mass. The purpose is to produce fracturing in the rock in order to increase permeability.

Hydraulic Hoisting — method of lifting ore or rock using water pressure.

In-situ Stress — the pressure that exists within the rock before any mining geometry altered the stress field.

Instability — failure of rock or structure.

Intersection — the point at which a drill hole enters a specific ore body, fault, or rock material.

Irad Gauges — a stress measurement device.

Jacks — a portable device used for exerting great pressure or for lifting a heavy body through a small distance.

Joints — a divisional plane or surface that divides a rock and along which there has been no visible movement parallel to the plane or surface.

Longwall — a method of mining flat bedded deposits, in which the working face is advanced over a considerable width at one time.

Loose — rock that must be barred down to make an underground workplace safe; also fragmented or weak rock in which underground openings cannot be held open unless artificially supported, as with timber sets and lagging.

Luminance — a measure of surface brightness that is expressed as luminous flux per unit solid angle per unit projected area b) physical brightness.

Lux — is a unit used in measuring light intensity.

Mass Blasting — technique of blasting wherein a large amount of ore is blasted at once.

Macro Environment — represents the total environment of the mine as opposed to the micro environment which is the individual stope or working area.

Mechanical Scaler — a machine used to remove loosened pieces of rock from an opening usually by hammering.

Metamorphism — any process by which consolidated rocks are altered in composition, texture, or internal structure by conditions and forces not resulting simply from burial and the weight of the subsequently accumulated overburden. Pressure heat and the introduction of new chemical substances are the principal causes of metamorphism.

Micro Environment — refers to the individual stope or working area.

Microseismic Monitoring — an electronic device used to measure subaudible noises or vibrations which occur in the rock, as a result of changes in stress. Can be used as indicators to rock failure.

Microseismic Percursors — small, subaudible noises detected to determine changes in stress that can precede failure.

Narrow Vein Mining — mining of an ore that is found in thin seams, often associated with gold mining.

Numerical Modelling — computer modelling such as "Boundary" or "Finite element" analysis. The mathematical simulation is used to determine stress levels in the rock in order to maximize production under safe working conditions. Potential areas of instability can be determined.

Open Stoping — stoping in which no regular artificial method of support is employed, although occasional props or cribs may be used to hold local patches of insecure ground. The walls and roof are self-supporting and open stopes can be used only where the ore and wall rocks are firm. The simplest open stopes are those in which the entire ore body is removed from wall to wall without leaving any pillars. The stoping of ore in this manner is usually confined to relatively small ore bodies, since regardless of the firmness of the ground, there is a limit to the length of unsupported span which will stand without breaking.

Overcoring — a method of measuring stress in the rock by determining the expansion of a piece of core by relieving the stress through drilling a larger diameter core around it.

Overhand Cut-and-fill — see cut-and-fill.

Pancake Jacks — thin, flat hydraulic jacks used in stress determination test monitoring.

Panels — a group of working places, usually operated as a unit, and separated from others by large pillars.

Permeability — the permeability of rock is its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the latter. It is measured by the rate at which a fluid of standard viscosity can move a given distance through a given interval of time.

Passive Supports — a type of ground support that applies no load to the rock, except in reaction to its movement, i.e. timber, cable bolt.

Pillars — an area of ore left to support the overlying strata or hanging wall in a mine. Pillars are sometimes left permanently to support surface works or against old workings containing water.

Point Load Test — method of determining the strength of a specimen of rock by applying a compressive load between two conical points.

Popping — snapping noise heard around the openings of a recently blasted rock face or in highly stressed areas.

Post Peak Strength Properties — the residual strength of a rockmass after failure.

Post Pillars — type of mining where very slender pillars are left to support the rock in conjunction with backfill.

Reefs — term used in Elliot Lake area to identify the stratigraphy of the ore body.

Refuge Stations — a place formed underground in which a man can take refuge in case of fire or other emergency.

Resin Bolting — a roof bolting technique in which the bolt is anchored in resin placed at the back of the hole in a plastic cartridge, which ruptures when the bolt is inserted. The resin sets and the bolt is held secure.

Richter — a logarithmic scale for expressing the magnitude of a seismic disturbance (as an earthquake) in terms of the energy dissipated in it with 1.5 indicating the smallest earthquake that can be felt, 4.5 an earthquake causing slight damage, and 8.5 a very devastating earthquake.

Rill — to mine ore so that it runs down a slope to a chute or loading level. Ore is said to be rilled to a chute when it is rolled down a slope left in mining.

Reamers — a hand tool or power tool for enlarging or smoothing a borehole. It is conical or cylindrical with cutting edges.

Rockbursts — an instantaneous failure of rock causing an expulsion of material at the surface of an opening or a seismic disturbance to a surface or underground mine.

Rockbolt — a rod or hollow cylinder, usually constructed of steel, which is inserted into pre-drilled holes in rock and secured for the purpose of ground control. Rockbolts are classified according to the means by which they are secured or anchored in rock. In current usage there are three main types, mechanical, grouted and friction.

Rock Bolt Plates — steel plates used on the end of a rockbolt to apply the force of the bolt to the rock.

Rock Mass Strength — refers to the overall properties of a large portion of rock with joints or other planes of weakness.

Rock Mass Classification — a system used to describe the rock mass properties.

Roof — the ceiling of any underground excavation.

Room and Pillar — a system of mining in which the distinguishing feature is the mining of 50 per cent or more of the ore in the first working. The remainder of the ore is left as pillars. The ore in the pillars may be mined by subsequent working.

Scaling Bar — a bar-like implement for removing loose rock.

Scaling — taking down of loose rock adhering to the solid face, back or walls.

Seismic Disturbances — these are vibrations of the rock caused by a release of energy from a change in stress.

Seismic Monitoring — the same as microseismic except on a larger scale in that it records larger events.

Seismic Events — earthquakes or vibrations caused by sudden failure of rock.

Service Openings — underground tunnels or raises used for the movement of men or materials.

Shafts — an excavation of limited area compared with its depth, made for finding or mining ore, hoisting and lowering men and material, or ventilating underground workings.

Shear — mode of failure of a body or mass whereby the portion of the mass on one side of a plane or surface slides past the portion on the opposite side.

Shear Tests — tests in laboratory or field tests to determine the shear strength of soil or rock samples.

Shotcrete — see gunite.

Shrinkage Mining — in this method the ore is mined out in successive flat or inclined slices, working upward from the level. After each slice is blasted down enough broken ore is drawn off from below to provide a working space between the top of the pile of broken ore and the back of the stope.

Sill Pillars — pillars left adjacent to a level drift in room and pillar mining.

Slippage — the movement of one mass of rock past another at a joint or fault.

Square Set — timber arranged in a cubic fashion to provide ground support. The set of timbers composed of a cap, girt and post. These members meet so as to form a solid 90° angle.

Slabbing Off — loose rock that forms usually on the walls of a stope or pillar due to high stress. These slabs are usually flat and parallel to the walls.

Spalling — loose rock developing on the walls or back due to high stress conditions distinguished from slabbing only in terms of magnitude, slabbing being the larger of the two.

Spitting — when a rock mass is under stress it breaks and ejects small fragments with considerable velocity.

Stereographic Projections — a graphic technique used to represent jointing and fracturing patterns in order to determine trends in the direction of jointing or fracturing. Used to identify wedges that are inclined to fall out.

Stopes — an excavation in a mine from which ore is being or has been extracted.

Strain Energy — the work done in deforming a body within the elastic limit of the material. Stored strain energy can be an indicator of the energy released when rock fails.

Stratigraphic Horizons — rock can exhibit layering which is referred to as stratigraphic horizons.

Stress — a mathematical term used to indicate the amount of load placed on the material, whether it be rock, wood, steel or backfill.

Stress Field — a descriptive term to indicate the pattern of stress existing in a particular area.

Stress Deformation — the load imposed on any material results in elongation or compression, which is called stress deformation.

Subsidence — the lowering of the strata, including the surface, due to underground excavations.

Supports — a general term for any timber, steel, concrete or structure erected to counteract rock failure of the roof or walls.

Syncline — a trough of stratified rock in which the beds dip toward each other from either side.

Tailings — the fine fraction discarded as waste from ore which has been processed.

Tectonic Forces — earth forces that act on a continent-wide basis to induce high horizontal stresses which cause earthquakes.

Tensile Strength — the ultimate strength of a material subjected to tensile loading. It is calculated by determining the tensile stress corresponding to the maximum load observed in the tension test.

Trackless Vehicles — rubber-tired vehicles as opposed to vehicles running on rails.

Triaxial Compression Tests — compression strength tests that simulate the three dimensional field stress that would be imposed on a rock in situ.

Tunnel — an underground passage.

Undercut-and-fill — a selective method of mining utilizing cemented backfill with stoping proceeding from the top of a mining block down in successive cuts.

Uniaxial Compression Tests — laboratory strength test on prepared rock core specimens.

Vertical Crater Retreat — (or Vertical Retreat Mining) — a bulk mining method that utilizes large diameter holes and mines successive cuts remotely by blasting and cratering the bottom of the drill holes. The ore body is mined from the bottom up.

Wedge Blocks — rock that is bounded by intersecting joint or fault planes and has a tendency to fall unless supported (i.e. bolting, pillars or screen).

Wire Mesh — a ground support method whereby the mesh or screen or fencing is intermittently supported by rockbolting. The purpose of the wire mesh is to contain small pieces of rock from falling from in between the bolting pattern.

Winze — a hoisting plant located underground.

Working Ground — rock under stress emits seismic energy. If the vibration is of a certain magnitude and frequency it can be heard and used to determine whether rock failure is eminent.

NOTES

The Report of the Provincial Inquiry into Ground Control and Emergency Preparedness in Ontario Mines

Ontario